United Nuclear Corporation

Gallup, New Mexico

Annual Review Report – 2018
Groundwater Corrective Action
Church Rock Site
Church Rock, New Mexico

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LIST OF ACRONYMS AND ABBREVIATIONS

ACL	alternate concentration limit
ALARA	as low as reasonably achievable
ARARs	applicable or relevant and appropriate requirements
BTV	background threshold value
COPC	constituent of potential concern
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
FS	feasibility study
ft/yr	feet per year
gpm	gallons per minute
GE	General Electric
GWPS	NRC Source Materials License groundwater protection standard
IC	institutional control
MCL	federal primary maximum contaminant level
mg/L	milligrams per liter
MNA	monitored natural attenuation
NA report	natural attenuation test report
NA test	natural attenuation test
NMED	New Mexico Environment Department
NNEPA	Navajo Nation Environmental Protection Agency
NRC	U.S. Nuclear Regulatory Commission
pCi/L	picocuries per liter
POC	point of compliance
POE	point of exposure
ROD	Record of Decision
SFS	supplemental feasibility study
SWSFS	site-wide supplemental feasibility study
SMCL	federal secondary maximum contaminant level
TDS	total dissolved solids
TTHMs	total trihalomethanes
TI	technical impracticability
UCL95	upper confidence limit of the mean at the 95% confidence level
UNC	United Nuclear Corporation
UPL95	upper prediction limit at the 95% confidence level
µg/L	micrograms per liter

SECTION 1
INTRODUCTION

On behalf of United Nuclear Corporation (UNC), Hatch has prepared this annual performance review of the groundwater corrective action at UNC's Church Rock Mill and Tailings Site near Gallup, New Mexico, pursuant to NRC Source Materials License 1475, Condition 30C. UNC has submitted an annual corrective action report at the end of each operating year since 1989. This report includes groundwater quality analyses and groundwater elevations for the first through fourth quarters of 2018.

This report focuses on both active remediation and the groundwater performance of the natural systems without active remediation. As indicated in the U.S. Environmental Protection Agency's (EPA's) First Five-Year Review Report (EPA, 1998), EPA recognized that the corrective action pumping systems were at, or reaching the limit of, their effectiveness and recommended that Technical Impracticability (TI) Waivers, Alternate Concentration Limits (ACLs), and Monitored Natural Attenuation (MNA) be used to complete the corrective action program (EPA, 1988b). Subsequent presentations and reports prepared to document the geochemical processes in the Southwest Alluvium (Earth Tech, 2000d and 2002b; Chester Engineers, 2009a) and the Zone 1 hydrostratigraphic unit (Earth Tech, 2000c; Chester Engineers, 2009a) showed that the natural geochemical mechanisms in these areas are at least as effective as the active remediation systems in controlling the migration of constituents of concern. This annual report describes how these natural processes are performing in these areas, and updates active remediation efforts and investigations in Zone 3, comprising the pumping of extraction wells along the northern front of seepage impact.

1.1 SITE LOCATION

The Church Rock Site ("Site") is located approximately 17 miles northeast of Church Rock, McKinley County, New Mexico (see Figure 1). Figure 2 is a Site map that shows the location of the decommissioned and temporarily idled extraction wells, the performance monitoring wells, the evaporation ponds, and the reclaimed tailings areas. Figure 2 also shows the Remedial Action Target Area for each hydrostratigraphic unit, where the impacts of tailings seepage were originally identified and corrective action was implemented (EPA, 1988a). Additional background information on Site facilities and activities is available in the previous annual reviews (Canonie Environmental Services Corp. [Canonie], 1989b, 1990, 1991, 1992, 1993 and 1995; Smith Technology Corporation, 1995 and 1996; Rust Environment and Infrastructure, 1997; Earth Tech, 1998, 1999, 2000e, 2002a and 2002c; USFilter, 2004; N.A. Water Systems, 2004, 2005, 2007a, and 2008a; Chester Engineers, 2009a, 2010a, 2011a, 2012b, 2013, 2014a, 2015a, 2016, 2017; and Hatch Chester, 2018).

1.2 CHRONOLOGY OF SITE EVENTS

Table 1A provides a chronological summary of important Site events from June 1977, when UNC milling operations began, to December 2018.

1.3 CORRECTIVE ACTION SYSTEMS

The corrective action systems for tailings seepage remediation were installed and began operating during the summer and fall of 1989. These systems have been decommissioned or, in the case of the Southwest Alluvium, shut off pending further evaluation, and performance monitoring is ongoing. The

Zone 1 system was decommissioned in July 1999 in accordance with the letter from the NRC dated July 30, 1999 (NRC, 1999a).

1.3.1 Southwest Alluvium

Southwest Alluvium Corrective Action System During 2018 Reporting Year

The Southwest Alluvium corrective action pumping system remained idle in 2018. Attenuation via natural geochemical processes has been shown to be at least as effective as pumping.

The Southwest Alluvium system was temporarily shut off in January 2001 to facilitate implementation of the natural attenuation test (NA test). The NA test was discussed and approved during the November 14 and 15, 2000, meeting in Santa Fe, New Mexico, and documented in the November 15, 2000, letter from the EPA. As requested by the EPA (2004a; and during meetings in Santa Fe on February 26, 2004, and at Church Rock on May 5, 2005), UNC continues to acquire groundwater quality data from wells in the Southwest Alluvium to monitor the effectiveness of natural attenuation and compare its performance to that of previous remedial efforts. This annual report presents a continuing assessment of the effectiveness of natural attenuation in the Southwest Alluvium. Performance monitoring is ongoing and is summarized in Section 1.4.1. Sampling results are summarized in Section 1.4.3 and discussed in detail in Section 2.3.

Changes to Southwest Alluvium Corrective Action System During 2018 Reporting Year

There were no changes to the Southwest Alluvium corrective action systems in 2018. A discussion of historical changes to the systems is provided in Section 2.1.

1.3.2 Zone 3

Zone 3 Corrective Action System During 2018 Reporting Year

Starting in 2005, extraction well pumping in Zone 3 has been carried out under a revised pumping regime. UNC continually revises and improves upon the Zone 3 remedial system. The Zone 3 corrective action system during 2018 comprised extraction from wells RW 11, RW 16, RW 17, RW A, NW 2, and NW 5 (discussed in Section 3 of this report). Performance monitoring is ongoing and is summarized in Section 1.4.1. Sampling results are summarized in Section 1.4.3 and discussed in detail in Section 3.3.

Changes to Zone 3 Corrective Action System During 2018 Reporting Year

There were no changes to the Zone 3 corrective action systems in 2018. A discussion of changes that occurred in prior years is provided in Section 3.1.

The following conclusions from previous Zone 3 corrective action systems and investigations inform our understanding of Zone 3 hydrogeology and its interactions with corrective actions systems.

- The corrective action system began operation in 1989. The Zone 3 system was shut down in June 2000 for maintenance and repairs. Prior to the Zone 3 system being brought back on-line, the agencies agreed that the existing system should be decommissioned (NRC, December 29, 2000 License amendment). This decision included a provision for UNC to submit a modified corrective action plan, an application for ACLs, or an alternative to the specific requirements of 10 CFR Part 40, Appendix A, if the License standards are not achievable. During 2006, UNC completed an extended pilot investigation (hydrofracture study) that indicated that the new pumping configuration had achieved nearly complete capture of the northward-advancing seepage-impacted water, while causing a notable improvement in the water quality within the northern tracking wells.

- Subsequent analyses indicated that the improvement of water quality in northern tracking wells was temporary and that there was a need for additional extraction wells to enhance groundwater capture. Extraction Well RW A and the five NW-series wells were installed to intercept and recover seepage-impacted water from Zone 3 in the northern part of Section 36 from 2007 to 2009.

- Pumping in the northernmost part of Zone 3 has created a mixing zone of background and seepage-impacted water. Groundwater quality along the northern tracking wells has oscillated between degrading and improving trends; therefore, the mapped position of the seepage-impacted water is dynamic.

- An alkalinity injection pilot study between April 2011 and June 2012 used injection Well IW A to enhance containment and to geochemically stabilize the seepage-influenced water (UNC's Remedial Design Report, Chester Engineers, 2010a). While alkalinity injection has been discontinued because both UNC and NRC believe it may lead to mobilization of uranium, pumping in Zone 3 continues, albeit characterized by very small, and diminishing, well yields.

- The revised Zone 3 pumping system has been declining in performance as anticipated by Appendix A of the ROD (EPA, 1988b), which states that "operational results may also demonstrate significant declines in pumping rates with time due to insufficient natural recharge of aquifers" and that "In the event that saturated thicknesses cease to support pumping, remedial activity would be discontinued or adjusted to appropriate levels." Declining pumping system performance has also been acknowledged in EPA Five-Year Review reports (e.g., EPA, 1998; EPA, 2008; EPA, 2013; EPA, 2018). All of the Zone 3 extraction wells have reduced yields that are below 0.3 gallons per minute (gpm) and the total volume pumped has decreased by 16 percent in comparison to 2017. Extraction wells having yields below the 1 gpm decommissioning criterion may be recommended for decommissioning in a revision to the pending License amendment request or in a future License amendment request.

1.3.3 Zone 1

Zone 1 Corrective Action System During 2018 Reporting Year

The Zone 1 system was decommissioned in July 1999 in accordance with the letter from the NRC dated July 30, 1999 (NRC, 1999a). Performance monitoring is ongoing and is summarized in Section 1.4.1. The performance monitoring results are summarized in Section 1.4.3 and discussed in detail in Section 4.3.

Changes to Zone 1 Corrective Action System During 2018 Reporting Year

There were no changes to the Zone 1 corrective action systems in 2018.

1.4 SUMMARY OF PERFORMANCE MONITORING AND SUPPLEMENTAL SAMPLING

1.4.1 Performance Monitoring

The groundwater performance monitoring plan and has been approved by the NRC and EPA and is described by the Corrective Action Plan (UNC, 1989a), Remedial Design Report (Canonie, 1989a) and Remedial Action Plan (UNC, 1989b). The program has been modified over time, as described in the annual reports (Canonie, 1989b, 1990, 1991, 1992, 1993 and 1995; Smith Technology, 1995 and 1996; Rust, 1997; Earth Tech, 1998, 1999, 2000e, 2002a, and 2002c; USFilter, 2004; N.A. Water Systems, 2004, 2005, 2007a, 2008a; Chester Engineers, 2009a, 2010a, 2011a, 2012b, 2013, 2014a, 2015a, 2016, 2017; and Hatch Chester, 2018), to adjust the monitoring requirements as the corrective action has progressed.

In accordance with the EPA's request in 1999, UNC developed a revised monitoring program that began with the second quarter 2000 sampling event. The revised program is documented in the letters dated January 13, 2000 (Earth Tech, 2000a), and April 26, 2000 (Earth Tech, 2000b). Details of the revised monitoring program for each hydrostratigraphic unit are provided in the performance-monitoring portion of the following sections and in the appendices.

UNC submitted a License amendment request (GE, 2015) and a subsequent amendment (GE, 2016b) that requested modifications to the monitoring program (see Section 1.5.1). As reported in the past three Annual Reports, UNC has determined that a few monitoring wells included in the performance monitoring program do not meet low-flow sampling performance requirements, which limits the ability to collect representative samples at these locations. Monitoring wells that do not meet operating criteria are considered candidates for decommissioning, which may be recommended to NRC in a revision to the pending License amendment request or in a future License amendment request.

The field pH, groundwater elevations, and laboratory analytical data collected from the third quarter of 1989 through the fourth quarter of 2018 are tabulated in Appendices A (Southwest Alluvium), B (Zone 3), and C (Zone 1). These data are compared to the current NRC License standards (updated in 2015) and the revised EPA cleanup levels (or "revised EPA cleanup standards") that were proposed by UNC and approved by EPA for use in preparation of Part III of the SWSFS (EPA, 2015). These standards have been used in the previous two annual reports; their continued use in this report is intended to reflect the most recent thinking that is critical to distinguishing background water from seepage-impacted water with respect to the site remedial alternative evaluations. The group of constituents that has NRC License standards is a subset of the group with EPA standards. A few of the EPA cleanup standards differ from the NRC License Standards (e.g., beryllium has a 0.050 mg/l NRC standard and a 0.004 mg/l EPA standard in Zone 3), but most are the same. Results that exceed either of the standards are highlighted (several of the EPA and NRC standards are identical).

Quarterly laboratory summary analytical data sheets for the 2018 operating year are included at the end of each appendix. UNC directly submits the following semi-annual reports to NRC (as a License requirement), which are copied to the other agencies: (1) groundwater, effluent and environmental monitoring report (including the full laboratory analytical reports and field parameter data), and (2) groundwater quality assurance report (including quarterly field data sheets as filled by hand).

1.4.2 Supplemental Sampling

Supplemental sampling has been conducted as a result of various agency requests as consistent with previous years. These are discussed in Sections 2.3, 3.3, and 4.3.

1.4.3 Summary of 2018 Performance Monitoring Results

Southwest Alluvium

The Southwest Alluvium NRC POC wells include GW 1, GW 2, GW 3, and EPA 28 in Section 3 and Well 632, EPA 23, and 509D in Section 2. Wells GW 2 and GW 3 can no longer be safely monitored (as of October 2015), because of their proximity to the unstable edges of the Pipeline Arroyo canyon.

During 2018, there were no exceedances of NRC License standards at any POC wells. There was one exceedance of a NRC License standard in seepage-impacted water within Section 2 (Pb-210 was detected at 6.8 pCi/L at Well 801 in the April sample). Nickel was detected at concentrations that exceeded the NRC License standard in four samples from background well SBL 1. EPA cleanup standards, for constituents that are not regulated by NRC or for which the EPA cleanup standard is different from the NRC License standard (e.g., nickel), were exceeded at the following locations (the numbers of quarterly exceedances are shown in parentheses):

- Well 632 – chloride (1) and manganese (4),
- Well 801 – manganese (4),
- Well 803 – manganese (4),
- Well 808 – manganese (3),
- Well 509 D – chloride (4) and manganese (4),
- EPA 23 – manganese (4),
- Well GW 1 – chloride (1), and
- Well SBL 01 (background well) – manganese (4) and sulfate (3).

Chloride, manganese and sulfate are non-hazardous constituent not regulated by NRC. No hazardous constituents exceeded revised EPA cleanup standards outside the UNC property boundary in seepage-impacted water.

With the exception of exceedances of the NRC License standard for uranium in samples from Well GW 3 in 2015, the groundwater quality at all POC wells has met the current License standards since January 2011. Historical exceedances of the current NRC standards at POC wells are infrequent and most occurred more than a decade ago.

Zone 3

Groundwater levels in Zone 3 continued to decline in 2018, indicating that the zone of anthropogenic saturation continues to diminish as the groundwater drains down the dip of the bedrock layers. Extraction well pumping since 2005 has locally accelerated the rate of water level decline in northern Zone 3 (e.g., in the vicinity of Well NBL 1, which has been effectively dry since February 2013). As in previous years, the declining water levels and reduced saturated thicknesses prevented sample collection at several Zone 3 monitoring wells during 2018.

The depiction of northern edge of the seepage-impact front for October 2018 is the same as that in 2016 and has been adjusted to encompass Well NW 5 and adjoin Wells NW 2 and MW 6. NW 1 is no longer shown to be within the seepage-impacted area based on its water chemistry. It is anticipated based on current concentrations that seepage-impacted groundwater water will eventually reach NW 2, and will be retarded by pumping from both Wells NW 2 and NW 5 (to the degree pumping can be maintained). UNC continues to evaluate the chemistry and water levels in the northern Zone 3 wells and may modify pumping rates to optimize the extraction system operations or cease operations.

The Zone 3 NRC POC wells (517, 613, 708, and 711) are within the fully impacted acidic "core" of the seepage-impacted water. The following constituents exceeded NRC License standards at one or more POC wells during the 2018 quarterly monitoring: beryllium, nickel, uranium, vanadium, and thorium-230. NRC License standards for beryllium, nickel, uranium, and gross alpha were also exceeded in seepage-impacted water at non-POC Well 717. Additionally, the NRC license standards for arsenic and combined radium (i.e., the combined activities of radium-226 and radium-228) were exceeded in samples from northern Zone 3 Well NW 3, which is interpreted to monitor predominantly background water.

Revised EPA cleanup standards were exceeded, at various locations, for beryllium, total dissolved solids (TDS), sulfate, aluminum, cobalt, and manganese during 2018 (i.e., for those constituents that are not regulated by NRC or for which the EPA cleanup standard is lower than the NRC License standard [e.g., beryllium]). Exceedances are further described by parameter in Section 3.3.4.

Zone 1

The Zone 1 NRC POC wells include Wells 604 and 614 within Section 2 and Wells EPA 4, EPA 5, and EPA 7 in Section 1. During the 2018 quarterly monitoring, only two constituents (nickel and TTHMs) were detected in POC well samples at concentrations that exceeded NRC License standards (Table C.1, Appendix C). Nickel concentrations exceeded the NRC License standard (0.070 mg/L) in all four quarters in Well 604 samples (within Section 2) and in all four quarters in EPA 7 samples (outside Section 2). The October 2018 TTHM concentration from POC Well 614 (within Section 2) exceeded the NRC License standard (80 µg/L). NRC License standards for TTHMs and nickel were also exceeded at non-POC Well 515 A during 2018.

EPA cleanup standards, for constituents that are not regulated by NRC or for which the EPA cleanup standard is different from the NRC License standard (e.g., nickel), were exceeded at the following locations (the numbers of quarterly exceedances are shown in parentheses):

- Well 515 A – TDS (4), sulfate (4), chloride (4), and manganese (4),
- Well 604 –cobalt (4) and nickel (1),
- Well 614 – chloride (4), and
- Well EPA 7 – cobalt (4).

The Well EPA 7 cobalt exceedances were the only EPA standard exceedances outside Section 2. Cobalt and nickel concentrations in Well EPA 7 were similar to those reported in 2017 but have increased with respect to other recent data.

1.5 STATUS OF REGULATORY REQUESTS

1.5.1 Ongoing from Previous Years

UNC has submitted a License amendment request (GE, 2015) and subsequent amendment to the License amendment request (GE, 2016b; GE 2017) to bring the license into conformance with recent advances that have been made with respect to the corrective action programs in the targeted areas. For example, UNC proposed to delete a License requirement to install and sample additional wells in Zone 3 and the Southwest Alluvium because the work has been completed. Well NBL 1 was constructed in Zone 3 in 2001 and Well SBL 1 was completed in the Southwest Alluvium in 2004. UNC also recommended that these wells be added to the quarterly sampling program.

For the Southwest Alluvium, in addition to the changes related to Well SBL 1, the License amendment request recommended that the corrective action program for the Southwest Alluvium contained in the current license should be formally discontinued and that monitoring and compliance requirements put forth in Conditions 30.A & 30.B be continued for the POC wells only. It was further proposed that Well GW 3 be omitted as a POC well and that the monitoring program in the Southwest Alluvium be reduced to include the remaining POC wells. The later amendment recommended that POC Well GW 2 also be omitted from the monitoring program and that the monitoring program in the Southwest Alluvium be reduced to include the remaining five POC wells and SBL 1. This is discussed in detail in Section 2.1. For Zone 1, the License amendment request recommended the removal of Well EPA 2 and POC Wells EPA 4, EPA 5, and EPA 7, all of which are located in Section 1. The License amendment request was supported by data from the previous sixteen years of post-shutdown monitoring, which indicated a gradual improvement in water from the Zone 1 Point-of-Compliance (POC) wells (GE, 2015).

As first reported in the 2015 Annual Report, UNC has determined that a few monitoring wells included in the performance monitoring program do not currently meet low-flow sampling performance requirements, which limits the ability to collect representative samples at these locations. Monitoring wells that do not meet operating criteria are considered candidates for decommissioning, which may be recommended to NRC in a revision to the pending License amendment request or in a future License amendment request.

A working draft of the Site-Wide Supplemental Feasibility Study (SWSFS) was submitted to EPA for comment on January 6, 2017. EPA originally directed UNC to prepare the SWSFS in 2006 (EPA, 2006); the SWSFS has been conducted as a three-stage process in keeping with the three structural components of EPA's FS process: Stage 1 - develop remedial action objectives (SWSFS Part I); Stage 2 - development and screening of alternatives (SWSFS Part II); and Stage 3 - detailed analysis of alternatives (SWSFS Part III) (EPA, 1988c). Each stage has been completed and approved before commencing with the next stage because each stage of evaluation builds upon the results and findings of its predecessor. EPA (2009) approved the SWSFS Part I (N.A. Water Systems, 2007b; 2008d; 2008e; 2008f). In July 2009, UNC submitted to EPA the revised Part II of the SWSFS (Chester Engineers, 2009b), which addresses the development and screening of remedial alternatives. Based upon a series of comments and responses (EPA, 2010; and Chester Engineers, 2010c), UNC submitted the Revised Site-Wide Supplemental Feasibility Study Parts I and II in April 2011 (Chester Engineers, 2011b). In October 2011, EPA considered Parts I and II to be complete and provided UNC with Notice to Proceed with development of the SWSFS Part III (EPA, 2011) subject to additional EPA comments (EPA, 2011; 2012).

Work on the third stage of the SWSFS (i.e., SWSFS Part III) was reinitiated in 2015 subsequent to the revision of Site groundwater standards. Those revisions came about through (1) the 2015 NRC License

Amendment (NRC, 2015), which updated the site NRC License standards (i.e., groundwater protection standards or GWPSs) on the basis of a background threshold value (BTV) statistical analysis process, and (2) EPA approval to use the UNC proposed cleanup levels, identified through an analogous BTV statistical analysis process, for the SWSFS (EPA, 2015; Chester Engineers, 2015b). UNC consulted with the agencies (e.g., see Chester Engineers, 2012a) regarding the most appropriate statistical methods to determine representative background water concentrations for the future long-term compliance monitoring program (where BTVs are appropriate for "not-to-exceed" monitoring results) and for the SWSFS. These concentrations differ from the mean-based background values utilized in the risk assessment context. UPL95s (upper prediction limit at the 95 percent confidence level) were selected as an appropriate statistical measure of BTVs for comparison with compliance samples. UNC utilized an extensive, current, and robust data set of groundwater quality analytical results from July 1989 through October 2007, inclusive, to develop UPL95s (or alternate UPLs, as appropriate) for each COPC in each hydrostratigraphic unit. Unlike the UCL95s (upper confidence limit of the mean at the 95% confidence level) developed for risk assessment purposes (N.A. Water Systems, 2008f), UPL95s are numerically developed by incorporating a specific, future compliance-monitoring program, involving a specific number of future sampling events and compliance-monitoring wells.

NRC issued License Amendment No. 52 (NRC, 2015) with the revised groundwater protection standards on April 9, 2015. UNC has identified a few typographical errors in the standards and has proposed corrections in the pending License amendment request (GE, 2015). The revised groundwater protection standards (including the proposed corrections) have been used for data comparisons in this annual report.

A few of the EPA cleanup standards differ from the NRC License Standards due to a slightly different comparison process and regulatory basis, including arsenic, beryllium, nickel, and selenium. The standard for uranium in the initial proposal to EPA was 0.3 mg/L, which is the same as the current NRC License standard. EPA and NMED concluded that they do not support the current standard for uranium in the Southwest Alluvium (0.3 mg/l) but, instead, support the BTV calculated for uranium based on the UPL95 statistical methodology (0.205 mg/l). UNC recommended instead that the EPA uranium standard be waived, because the source of uranium in both background and seepage-impacted water in the Southwest Alluvium was not tailings seepage, but mine water, permitted to contain uranium concentrations up to 2 mg/l, discharged to Pipeline Arroyo for 17 years. The proposed uranium standard is further discussed in Section 2.3.5. However, in this report (as in the 2015 and subsequent Annual Reports, and SWSFS Part III) a standard of 0.3 mg/L has been used for comparisons.

These agency actions to revise the background standards lessen one of the technical impediments (GE, 2009) to eventual Site closure which stated that "long-term monitoring data and basic geochemical considerations reveal some cleanup objectives to be unattainable." For most parameters, the establishment of background threshold values through statistical analysis will incorporate and account for the natural geochemical evolution of pre- or post-mining, pre-tailings (i.e., background) groundwater quality and distinguish it from the chemical characteristics of post-mining, post-tailings groundwater (i.e., water that is subject to the corrective action program).

1.5.2 Changes During Reporting Year

UNC has initiated a process to permit, drill, construct, and operate monitoring wells north of the Section 36 boundary on the Navajo Reservation (Figure B-2 in Appendix B), as requested by the Navajo Nation EPA (NNEPA, 2013). The installation of these wells is recommended to support the adoptions of waivers, alternate standards or other administrative controls to close the corrective action program.

Information obtained during 2018 suggested that Zone 3 may be deeper at the proposed monitoring locations than previously understood, which would reduce the number of wells needed to meet the monitoring objectives. Consequently, the monitoring well plan was adjusted to comprise the installation of three wells, followed by evaluation of geologic and water quality data to confirm that the monitoring objectives have been met. It is anticipated that the wells will be installed during 2019.

SECTION 2
SOUTHWEST ALLUVIUM

2.1 CORRECTIVE ACTION SUMMARY

The Southwest Alluvium corrective action pumping system remained idle in 2018. Attenuation via natural geochemical processes has been shown to be at least as effective as pumping. There were no exceedances of current NRC License standards or revised EPA cleanup standards by a hazardous constituent in seepage-impacted water outside the UNC property boundary in 2018.

The Southwest Alluvium system was temporarily shut off in January 2001 to facilitate implementation of the NA test. The NA test was discussed and approved during the November 14 and 15, 2000, meeting in Santa Fe, New Mexico, and documented in the November 15, 2000, letter from the EPA. As requested by the EPA (2004a; and during meetings in Santa Fe on February 26, 2004, and at Church Rock on May 5, 2005), UNC continues to acquire groundwater quality data from wells in the Southwest Alluvium to monitor the effectiveness of natural attenuation and compare its performance to that of previous remedial efforts. In October 2015, UNC submitted a License amendment request (GE, 2015) that seeks to terminate the Southwest Alluvium corrective action program because the groundwater quality at all POC wells had remained at or within the standards set in the license for at least the previous nine quarters (through July 2015), with the exception of uranium concentrations in Well GW 3 (which does not provide representative samples, see Section 2.3.5). This annual report presents a continuing assessment of the effectiveness of natural attenuation in the Southwest Alluvium.

2.2 MASS OF CHEMICAL CONSTITUENTS REMOVED

The mass of chemical constituents removed during active groundwater recovery operations was calculated for the period from November 1989 through January 2001. These calculations were presented in the previous annual reviews, and the final summary was presented in the 2001 Annual Review (Earth Tech, 2002a).

2.3 PERFORMANCE MONITORING EVALUATION

2.3.1 Water Level Evaluation

The current water level monitoring component of the Southwest Alluvium performance monitoring program is summarized in Table 1B and comprises quarterly monitoring of water levels in 16 wells (see Figure 2 and Figure A-1 [Appendix A]). Well SBL 1, a downgradient background (i.e., not seepage-impacted) well installed in 2004 at the request of EPA (November 2000) is not a formal requirement of the performance monitoring program, but it is also monitored for water level. POC Wells GW 2 and GW 3 can no longer be safely monitored (as of October 2015), because of their proximity to the unstable edges of the Pipeline Arroyo canyon (see photographs in Appendix A, Figure A-2). UNC has submitted a License amendment request (GE, 2015) and a subsequent amendment (GE, 2016b; GE, 2017) to NRC that would add Well SBL 1 to the performance monitoring program and remove POC Wells GW 2 and GW 3.

Groundwater is present in the Southwest Alluvium as a result of the infiltration of water historically discharged into the Pipeline Arroyo after having been pumped from the Quivira and NECR mines to facilitate their construction and operation. This water percolated into the alluvium and created temporary saturation near the tailings impoundments, which has diminished gradually over time. The detailed history of infiltration of mine-dewatering groundwater, into the alluvium and the subcrop of Zone 3 and Zone 1, has been incorporated into the Site groundwater flow model (Chester Engineers, 2012c, 2014b). This temporary saturation caused by discharged mine-dewatering groundwater is the recognized Southwest Alluvium background water (EPA, 1988a; 1988b; 1998; 2008). The level of saturation has been declining since groundwater pumping in connection with historical mine operations ceased in 1986. As a result, the flanks of the alluvial valley and the northern property boundary alluvium have completely de-saturated and, by 2000, a 31 percent saturation loss had been observed further to the south (Earth Tech, 2000d). The saturated thickness calculated for each performance monitoring program well during the October 2018 monitoring event is provided in Table 3. During 2018, all well measurements have shown decreasing groundwater elevations (with small fluctuations), indicating that the groundwater flux continues to decline with the shrinking of the zone of saturation.

The Southwest Alluvium potentiometric surface map for the October 2018 monitoring event is shown in Figure 3A. This figure shows a local, eastward turn to the saturated alluvium, beneath the northwestern part of the South Cell, reflecting the presence of a relatively high area (bulge) in the bedrock surface between Wells 509 D and EPA 23. This bulge encompasses the area including the “Nickpoint” along Pipeline Arroyo. The Nickpoint (Figure 3A) has been referred to in earlier reports. It is a local rim-like bedrock high along the arroyo, below which the streamway becomes incised and continues downgradient as Pipeline Canyon.

Figure 3B shows a contour map of saturated thickness in the Southwest Alluvium based on the October 2018 monitoring event results. This map was developed by integrating the potentiometric surface with a structure contour map of the base of the alluvium (and thus does not involve directly contouring the posted values of saturated thickness). The distribution of the groundwater suggests the likelihood that the northern portion of the groundwater system, upgradient of the Nickpoint and including Well 509 D, may have become “detached” or ponded (i.e., lost hydraulic continuity) from the groundwater to the south. Such detachment may occur along the local high in the top of bedrock that causes the saturated alluvium to jog to the east near the Nickpoint (Figure 3B). The underlying data density is not sufficient to allow certainty on this issue. However, it is likely that this will eventually happen both to the north of the Nickpoint and in a large depression, along the top of bedrock, that is west of the South Cell and below the Nickpoint.

Figure 4 shows water levels over time in Southwest Alluvium wells, illustrating the overall long-term trend of decreasing levels as water continues to drain from the alluvium. Note that in 2007, the water level in EPA 23 (below the Nickpoint) became higher than the level in 509 D (above the Nickpoint). The slope (rate) of decline above the Nickpoint (509 D) in Figure 4 is greater than the rate of decline below the Nickpoint (EPA 23) prior to January 2007, but later slowed relative to EPA 23, such that the water level elevations are similar, and rates of decline are virtually identical. Similarly, since 2015, the water level in Well SBL 1 has been higher than the level in Well 624 and since July 2018, the Well SBL 1 water level has been higher than the level in Well EPA 25. The water level in SBL 1 has a lower rate of decline than the other wells over time, possibly because of well construction or hydrogeologic differences.

Water levels in the vicinity of the pumping wells increased temporarily after they were turned off in January 2001 for the start of the NA test (see Figure 5). Water levels in the former pumping wells have since stabilized at elevations similar to those measured in nearby monitoring wells. A summary of operational data for the Southwest Alluvium extraction wells is provided in Table 4.

Southwest Alluvium groundwater flows to the southwest, along the Pipeline Arroyo. Based on calculations of the volume of background groundwater drainage through the valley in comparison to historical pumping rates, the drainage had exceeded the total pumping volume throughout the corrective action period by 30 percent or more (Earth Tech, 2000d). Groundwater pumping did not fully contain seepage-impacted water; however, it is important to realize that hydraulic containment is not a necessary feature of the corrective action program in the Southwest Alluvium because of the strong geochemical attenuation that occurs naturally.

2.3.2 Water Quality Evaluation and Current Extent of Seepage-Impacted Water

The current water quality monitoring component of the Southwest Alluvium performance monitoring program is summarized in Table 1B and comprises quarterly monitoring of water quality in 14 wells. Well SBL 1, a hydraulically side-gradient background (i.e., not seepage-impacted) well is not a formal requirement of the performance monitoring program, but it is also monitored for water quality. As described in Section 2.3.1, POC Wells GW 2 and GW 3 can no longer be safely monitored (as of October 2015), because of their proximity to the unstable edges of the Pipeline Arroyo canyon. UNC has submitted a License amendment request (GE, 2015) and a subsequent amendment (GE, 2016b) that would add Well SBL 1 to the performance monitoring program and remove POC Wells GW 2 and GW 3 from the monitoring program. It further recommends continuing the current monitoring and compliance requirements put forth in Conditions 30.A & 30.B for the POC wells only.

As indicated in previous annual reports, UNC has determined that monitoring Wells GW 3 and 632 (both are POCs in the Southwest Alluvium) do not meet performance criteria associated with low flow groundwater sampling methods, which limits the ability to collect representative samples. The alluvium also has very limited saturated thickness at Well GW 3, which may have contributed to elevated constituent concentrations (i.e., consistent with the hypothesis developed by NRC [1996], that dissolved salt concentrations increase as saturation levels decline and the aquifer system dries out). Monitoring wells that do not meet operating criteria are considered candidates for decommissioning, which may be recommended to NRC in a revision to the pending License amendment request or in a future License amendment request.

A summary of constituents detected in the Southwest Alluvium in the October 2018 monitoring event is provided in Table 2. Historical groundwater quality and groundwater elevation data through October 2018 are provided in Appendix A (Table A.1). Both tables also include the Southwest Alluvium NRC GWPSs and the revised Southwest Alluvium EPA cleanup levels to facilitate direct comparison with the groundwater data. These groundwater standards were revised through the development of updated BTVs by statistical analysis. NRC issued a License amendment to update site GWPSs (NRC, 2015) and EPA approved use of the UNC proposed cleanup levels (EPA, 2015) for remedy alternative evaluation in the ongoing SWSFS.

No hazardous constituents exceed current NRC License standards or revised EPA cleanup standards outside the UNC property boundary in seepage-impacted water sampled during 2018. With the exception of the 12 uranium NRC License standard exceedances in samples collected from Well GW 3 between July 2012 and July 2015 (discussed more below), the groundwater quality at all POC wells has met the current License standards since January 2011. There was one exceedance of the NRC License standard for Pb-210 in the sample from Well 801 during April 2018.

The area currently containing seepage-impacted groundwater in the Southwest Alluvium is shown on Figure 6. As explained more fully below, common ion geochemistry in the delineated area has been changed by the neutralization of tailings seepage migrating through the alluvium. The area of seepage impact extends southwest along the western margins of the North, Central, and South Cells, and continues approximately 1,500 ft across the southeastern corner of adjacent Section 3 and approximately 190 ft into the north-central portion of adjacent Section 10. The total length of the area is approximately 6,600 ft.

Historically, only two constituents (sulfate and TDS) consistently exceeded their historical EPA standards in the Southwest Alluvium seepage-impacted groundwater outside the UNC property boundary in Sections 3 and 10. Sulfate and TDS also exceeded the historical EPA standards in the background water (Wells 627, EPA 28, and SBL 1). The majority of TDS is composed of sulfate; therefore, TDS concentrations mimic sulfate concentrations (Earth Tech, 2000d). In comparison to the revised EPA standards, there were no exceedances of TDS in any Southwest Alluvium wells during 2018 and sulfate exceedances occurred only in three samples from background Well SBL 1 (Figure 7).

Historical sulfate concentrations through October 2018 are shown graphically in Figure 7. This figure shows that the long-term concentrations in most wells have remained approximately steady with the following exceptions: (1) the concentrations in Wells 801 and 509 D decreased in January 2000 and October 1999, respectively, and have since remained, with some recent variability, at relatively lower levels; and (2) the concentrations in Well GW 2 (no longer sampled beginning in October 2015) have shown an overall increasing trend since the shutoff of pumping, although the increase appears to have moderated starting in July 2010 and is well below the revised EPA standard. The light-gray data points in the upper right part of this chart represent the sulfate measurements from Well SBL 1 (post-mining/pre-tailings; i.e., background water quality). In October 2018, as in all previous quarters, this well had the highest sulfate concentration of any well in the Southwest Alluvium, including the nearest, hydraulically upgradient Well 624 which is impacted by seepage. As shown on Figure 7, the only exceedances of the revised EPA cleanup level for sulfate were found in Well SBL 1 in the January, April, and October 2018 samples.

Where they occur, locally increasing trends in concentrations of common dissolved ions are unrelated to tailings seepage; they derive from the reaction of the anthropogenic recharge water with natural alluvium materials. Heterogeneous distribution of the soluble alluvium minerals is the most significant factor affecting the intra-well and inter-well variations in the concentrations of common dissolved ions. Increasing levels of common dissolved ions may mean that either (1) the diminishing saturation is being accompanied by increasing dissolved ion concentrations (consistent with the hypothesis developed by NRC, 1996), and/or (2) more of the alluvium minerals are being dissolved (also discussed by NRC, 1996). As shown by UNC's MINTEQ studies, the alluvium groundwater is generally at saturation (or in equilibrium) with respect to calcite, gypsum, and other soluble mineral salts.

Figure 8 is a bicarbonate isoconcentration map of the Southwest Alluvium during October 2018. As explained in earlier annual reports and in the first natural attenuation test report (NA report; Earth Tech, 2002b), bicarbonate concentration is the main attribute by which the presence and extent of seepage-impacts can be evaluated. The seepage-impacted area has near-neutral pH values as a result of the high capacity of the alluvium to neutralize the acidic tailings seepage. The neutralization capacity has also prevented the migration of metals from the former tailings impoundments. The neutralization capacity is strongly tied to relatively large amounts of calcite ($CaCO_3$) in the alluvium that is available for buffering: Canonie (1987, Table 4.4) reported measured alluvium $CaCO_3$ fractions of 2.58 percent in a sample collected during drilling of Well EPA 23; 0.77 to 0.28 percent near the Pipeline Arroyo Nickpoint; and 0.02 to 12.6 percent elsewhere.

The bicarbonate isoconcentration contours shown in Figure 8 illustrate the zone of seepage impact with fine resolution. Prior to the 2004 Annual Report, the seepage impact zone was based on assumptions of seepage migration rates and delineated by a line encompassing estimated bicarbonate concentrations exceeding 1,000 mg/L. It has since been recognized that there is a core of more significant impact (bicarbonate concentrations exceeding 2,000 mg/L) surrounded by progressively less seepage-impacted groundwater (approximated by the 1,000 mg/L contour).

The groundwater quality characteristics of the non-seepage-impacted (background) samples from Well SBL 1 differ in several important aspects from seepage-impacted water (refer to Figure 9 and Appendix A). Well SBL 1 is located hydraulically side-gradient of the seepage-impacted water within background water (non-seepage-impacted water of post-mining/pre-tailings origin). Well 624 is the closest seepage-impacted well (500 ft) to Well SBL 1 (Figure 8). Although the following observations compare these two wells in particular, they apply equally well to most, if not all, of the seepage-impacted wells:

- Well SBL 1 contains a magnesium-sulfate (Mg-SO4) type water while Well 624 contains a calcium-sulfate (Ca-SO4) type. The presence of much higher magnesium concentrations in SBL 1 suggests the dissolution of magnesium salts in the alluvium (for example, epsomite or magnesite) during the earlier flushes of mine discharge water down Pipeline Arroyo.

- The alkalinity (bicarbonate or HCO3) of Well SBL 1 water is much less than the seepage-impacted water in Well 624 samples. High bicarbonate concentrations are indicative of the neutralization of acid tailings liquids by dissolution of carbonate minerals. Chloride concentrations in Well SBL 1 are also lower than those indicative of seepage-impacted groundwater (see Appendix A and the discussion below in Section 2.3.4).

- Geochemical speciation calculations using EPA's MINTEQ numeric modeling code confirm that several aluminum-hydroxide (Al-OH) salts are oversaturated in Well SBL 1 water while they are not in Well 624 water. This suggests that the water farther downgradient than the seepage-impacted water may show signs of the dissolution of soluble salts associated with earlier flushes of the alluvium.

- Well SBL 1 water and seepage-impacted water are alike in that both appear to be in approximate equilibrium with an assemblage of Ca-SO4 (as anhydrite or gypsum), magnesium-carbonate (Mg-CO3, as magnesite or dolomite), and calcium-carbonate (CaCO3, as calcite). MINTEQ simulations show that when acidic water (i.e., tailings liquid) is exposed to these mineral phases, there is a geochemical shift toward higher bicarbonate concentrations and lower sulfate concentrations (e.g., Well 624) than would occur in the absence of the acid (e.g., Well SBL 1). The result is a tendency to increase bicarbonate, decrease sulfate, and maintain constant calcium concentrations as the seepage-impact front migrates.

An interesting consequence of the migration of the seepage front should be that the ratio of sulfate to bicarbonate is at a minimum where the tailings seepage front meets and reacts with non-seepage-impacted areas in the alluvium. Sulfate concentrations are greater within the core of the seepage-impacted areas because sulfate concentrations in the tailings liquids were up to two orders-of-magnitude greater than the amount that remains in the seepage-impacted water. A significant amount of gypsum had to precipitate in proximity to the concentrated tailings liquids to cause the reduction of sulfate concentrations to levels that are in equilibrium with gypsum. Out in front of the seepage-impacted water, the dissolution of the alluvium gypsum (or anhydrite) produced sulfate in the background water at levels above the historical standard (2,125 mg/L). The revised EPA cleanup level of

5,815 mg/L is exceeded only at Well SBL 1; all seepage-impacted wells have sulfate concentrations below this level.

These same conceptual geochemical models, for both the earlier evolution of the background water chemistry and the later, progressive evolution of seepage-impacted water chemistry, can be constructively applied to consideration of the groundwater chemistry data shown in Figure 9. Figure 9 shows the primary components of TDS in the Southwest Alluvium in the October 2018 monitoring event. The chart arrangement of the wells runs approximately from those located upgradient, on the left of the chart, to those downgradient on the right. Three background Wells (627, EPA 28, and SBL 1) show relatively elevated sulfate combined with high ratios of sulfate to bicarbonate. Former background Well EPA 25 shows a relatively lower ratio of these two parameters in conjunction with relatively elevated calcium. The long-term geochemistry in the vicinity of Well EPA 25 (Appendix A) suggests that fully seepage-impacted waters have been nearby, consistent with its hydraulically side-gradient location with respect to the bicarbonate isoconcentration map in Figure 8. Figure 9 shows the highest contribution of sulfate to the TDS is in Well SBL 1 (this well historically has had higher sulfate concentrations than any other Southwest Alluvium well), a well which also shows the lowest contribution from bicarbonate (HCO3) and very low contributions from chloride (“Chl” on the figure) and calcium (Ca). These observations and analysis confirm that the current extent of seepage-impacted water has not reached Well SBL 1.

Neither the seepage-impacted water nor the background water that has not been impacted by seepage meets New Mexico water quality standards for TDS, but all samples are well below the revised EPA cleanup level of 10,376 mg/L (Table 2, Figure 10). In some respects, particularly regarding sulfate concentrations, the seepage-impacted water may be viewed as an improvement compared to the non-seepage-impacted (background) water. Groundwater quality within the Southwest Alluvium is further discussed in Section 2.3.5.

Unlike seepage-impacted waters in Zones 1 and 3, the pH of the Southwest Alluvium seepage-impacted water is nearly neutral. Consequently, there have been very few exceedances of the revised metals or radionuclides standards within the seepage-impacted water; recent exceptions include the following:

- Exceedance of the NRC License standard for uranium in 12 of the last 13 samples from Well GW 3 (not sampled since July 2015).
- Exceedances of the EPA cleanup standard for manganese (a non-hazardous constituent not regulated by NRC) at locations within the property boundary (Table 2).
- A slight exceedance of the NRC License standard for Pb-210 (5.9 pCi/L) in the sample from Well 801 in April 2018 (6.8 pCi/L). This result is unusual in that it was the only Pb-210 detection in the 2018 Southwest Alluvium samples and there have only been 13 exceedances of the current standard in Southwest Alluvium samples since 1989. The only previous exceedance at Well 801 was reported in January 1997. There is no basis to infer that this Pb-210 result reflects any impact of tailings seepage.

These exceedances are discussed further in Section 2.3.5.

Background water sampled at downgradient Well SBL 1 in October 2018 had four exceedances of nickel (range 0.081 to 0.092 mg/L, higher than the NRC License Standard of 0.078 mg/L but less than the revised EPA cleanup level of 0.2 mg/L) and manganese (range 3.63 to 4.4 mg/L, higher than the revised EPA cleanup level of 2.1 mg/L). These metals exceedances are unrelated to seepage impact to the groundwater, because seepage-impacted water has not yet migrated to this location. Therefore, they should be viewed as a background condition, i.e., of post-mining/pre-tailings origin and age. The NRC's statistical evaluation of background water quality led to their recommendation that manganese, sulfate, and TDS should not be regulated Site constituents and they should not be used as bases for corrective action (NRC, 1996).

Two other constituents are present at concentrations that historically have exceeded standards primarily within the property boundary:

- Chloroform – In August 2006, the NRC modified the Site License to change the former chloroform standard of 1 µg/L to a TTHMs standard of 80 µg/L (NRC, 2006), which is equivalent to the EPA standard. Starting with the October 2006 sampling event, the laboratory has analyzed for TTHMs – all four component compounds (of which chloroform is one) are measured, and almost all Site groundwater samples (including the Southwest Alluvium) show that the TTHMs concentration equals the chloroform concentration (i.e., chloroform is the only TTHM compound present). In occasional discussion of "chloroform concentrations" in this report, the reader should bear in mind that the NRC/EPA standard (and laboratory analysis) of relevance is now for TTHMs and not solely for chloroform as was previously the case. Table 2 shows that during the October 2018 monitoring event, Southwest Alluvium TTHMs were detected at levels far below the NRC/EPA standard of 80 µg/L in the following wells: 632, 802, and GW 1. There were no chloroform exceedances at any Southwest Alluvium location during 2018 (Appendix A).
- Chloride – Chloride is a non-hazardous constituent that is not regulated by NRC. In 2018, chloride concentrations exceeded the EPA cleanup standard (250 mg/L) only at Well 509 D, (located near the Central Cell within Section 2) and in the April 2018 samples collected from Wells 632 (257 mg/L) and GW 1 (255 mg/L). Chloride at Well 509 D has exhibited an overall stable trend since 1999 with fluctuations ranging from 278 to 462 mg/L (see Figure 12). There have been occasional slight exceedances of the EPA chloride standard outside Section 2 in Well GW 1. Chloride concentrations are discussed more in Section 2.3.5.

2.3.3 Rate of Seepage Migration

Earth Tech (2002b) analyzed concentration trends of chloride and bicarbonate to infer the rate of constituent migration. Seepage impacts were observed to have migrated beyond the Site property boundary by 1982, based primarily on the exceedances of historical standards in the seepage-impacted water for sulfate and TDS. However, bicarbonate and chloride have been determined to be the more effective indicators of seepage impact for reasons described in Section 2.3.2.

Groundwater velocity calculations have been made to update the estimate of the rate of downgradient seepage-impact transport. These estimates are Darcy seepage velocities equal to the product of the hydraulic conductivity and the hydraulic gradient, divided by the effective porosity. The resultant groundwater velocities are upper-bound estimates of constituent transport velocities because no retardation or attenuation factors are applied.

Table 5 shows Southwest Alluvium groundwater velocities determined based on groundwater elevation measurements made at Wells 805, 624, 627 and SBL 1 during the fourth 2018 groundwater monitoring event (i.e., October, 2018). Upper and lower estimates of seepage velocity are based on a range of effective porosities adopted from Canonie (1989b) and Earth Tech (2002b). The average calculated velocities are effectively based on a median porosity estimate of 0.31. Application of the mean hydraulic conductivity value of 3.69 x 10^{-3} cm/sec formerly used by Earth Tech (2002b) results in the prediction that seepage impact should already have arrived at Well SBL 1, which is not the case. The new hydraulic conductivity value, used first in the 2012 Annual Report (Chester Engineers, 2013) is 2.5 x 10^{-3} cm/sec (replacing the former value of 2 x 10^{-3} cm/sec), which was determined to be an appropriate value based on groundwater flow model calibration for the Southwest Alluvium (Chester Engineers, 2012c, 2014b). The new value is 25 percent larger than the former value and this should generally be expected to result in higher calculated velocities than before.

The average groundwater velocity from Well 624 to Well SBL 1 was not calculated. The average calculated velocity for this well pair for October 2014 was 8 ft/yr, for October 2013 was 19 ft/yr, and for October 2012 was 11 ft/yr. With the exception of the increased velocity in 2013, the velocity has consistently decreased in the prior four years, which resulted from declining water levels and horizontal hydraulic gradients between this well pair. The water level in SBL 1 has a lower rate of decline than Well 624 over time. In 2015, the horizontal hydraulic gradient between these wells became negligible and likely reversed, resulting in a gradient flowing from SBL 1 toward Well 624. Additionally, the Well SBL 1 water level elevation has been higher than the level in Well EPA 25 since July 2018.

Table 5 indicates that the calculated average velocity for well pair 805 and 624 for October 2018 is slightly higher than the 2014 through 2017 calculations (59 ft/year in October 2018; 57 to 58 ft/yr in previous years) and the calculated average velocity for well pair 805 and 627 in October 2018 (69 ft/yr) is consistent with those calculated for previous years.

The downgradient limit ("nose") of the 1,000 mg/L bicarbonate isoconcentration contour shown in Figure 8 has been modified from that presented in the 2014 through 2017 Annual Reports. Now that the piezometric elevations in SBL-1 and points east are depicted as being higher than in Well 624 (in Figure 3A), Well SBL-1 is no longer downgradient of the "nose" of the plume. Instead, hydraulic gradients are to the west south-west and the "nose" of the 1,000 mg/L bicarbonate isoconcentration line is to the north of SBL 1, as depicted on Figure 8. The saturated thickness map in figure 3B is also consistent with this interpretation, because the greater saturated thickness to the north of SBL-1 implies that the mass flux would be greater in the area north of SBL-1.

2.3.4 Continuing Assessment of Southwest Alluvium Natural Attenuation and Earlier Technical Impracticability Waiver Request

UNC conducted a scheduled NA test from February 2001 to July 2002 to determine whether shutting off the Southwest Alluvium extraction wells would adversely affect water quality. The Southwest Alluvium extraction wells were shut off in January 2001 for the duration of the test. The NA report was submitted to the EPA, NMED, and NRC on November 4, 2002 (Earth Tech, 2002b). The NA report concluded that turning off the extraction wells does not have an adverse effect on water quality and that the natural system is as effective as, or more effective than, pumping for controlling the migration of the constituents of concern. EPA has not made a definitive conclusion about this (EPA, 2018); therefore, additional monitoring is being performed.

The Technical Impracticability (TI) evaluation in the NA report concluded that natural conditions maintain sulfate and TDS concentrations at non-seepage-impacted background concentrations, which were nonetheless greater than previous EPA cleanup standards. However, because the revised EPA cleanup standards (issued in 2015) better account for background geochemistry, the conclusion has been revisited. When compared to the revised EPA cleanup levels, all TDS and sulfate concentrations, with the exception of sulfate in background Well SBL 1, are below the standards. Additional discussion of the TI evaluation is included in previous annual reports.

2.3.5 Reassessment of the Performance of the Natural System

The NA report (Earth Tech, 2002b) used nonparametric trend analysis to determine whether increases in contaminant concentrations occurred during the NA test and whether the changes were significant. Upward concentration trends were identified for bicarbonate, chloride, and TDS, although bicarbonate was evaluated as an indicator parameter only, not as a constituent of concern. These increases were attributed to the elimination of the partial capture provided by the extraction wells. No change in trend was observed for the sulfate concentrations because these are naturally equilibrated with gypsum. However, after the submittal of this report in 2002, Wells GW 2 and GW 1 had shown increasing sulfate trends; such increasing major ion concentrations reflect the influence of declining water levels and/or increased dissolution of the alluvium materials (NRC, 1996). The NA report (Earth Tech, 2002b) also concluded that there was no change in trend for manganese, chloroform, or uranium. It was concluded from these analyses that, although seepage-impacted water continues to migrate as shown by upward trends in bicarbonate, the migration of metals and radionuclides is arrested by attenuation processes (i.e., adsorption and precipitation). Continued groundwater quality monitoring through October 2018 supports this conclusion for the vast majority of analytes in virtually all monitoring wells.

Table 6 shows the predicted performance of natural attenuation in the Southwest Alluvium. In summary, sulfate and TDS concentrations in seepage-impacted water are expected to meet the revised EPA cleanup standards that take into account the gypsum equilibrium in background groundwater. Entries in Table 6 include evaluation of background water quality in Well SBL 1, as well as our understanding of the geochemical systems associated with both background water and seepage-impacted water. Manganese is expected to meet the revised (lower) EPA standard in seepage-impacted water outside Section 2 but exceed the EPA standard in both seepage-impacted wells within Section 2 and background Well SBL 1 (outside Section 2, in Section 10). Metals and radionuclides in seepage-impacted water are expected to meet their respective standards through attenuation by neutralization and adsorption. There was an unusual exceedance of the Pb-210 NRC License standard in the April 2018 sample from Well 801. However, Pb-210 was not detected in two subsequent samples from Well 801 in July and October 2018. Chloride concentrations (which are not regulated by NRC) in seepage-impacted water outside Section 2 typically meet the standard (with three minor exceptions at Well GW 1 between 2015 and 2018) but are expected to continue to exceed the EPA cleanup standard, particularly at upgradient Well 509 D, within Section 2. The individual indicator parameters and constituents of concern are discussed below.

Calcium and Bicarbonate

Calcium and bicarbonate are non-hazardous constituents and indicator parameters that are not regulated by NRC or EPA. Figure 13 illustrates the long-term stability of calcium and bicarbonate concentrations at Wells 627 and EPA 28, which have been considered examples of background wells that have not been impacted by tailings seepage, as determined based on their bicarbonate concentrations below 1,000 mg/L. The bicarbonate concentration in Well EPA 28 decreased “step-wise” from approximately 800 mg/L to approximately 400 mg/L near the end of 2015 and has restabilized. These results suggest that although the bicarbonate plume may have been approaching EPA 28, bicarbonate concentrations did not rise to levels indicative of seepage-impact under the site conceptual model. Subsequently, in the 2014 to 2015 timeframe, the bicarbonate band shifted away from EPA 28. Calcium concentrations in these two wells have been essentially the same through time. Figure 13 shows that during the onset of seepage impact in Well 624 (indicated by the increasing bicarbonate), the calcium concentration increased by approximately 100 mg/L and then re-equilibrated at a concentration of 650 to 700 mg/L. Under changed groundwater quality flux, calcium concentrations remain fixed in the presence of calcite and gypsum by the Phase Rule; the long-term consistency of calcium concentrations in the Southwest Alluvium attests to the established equilibrium between the groundwater and these minerals. In general, calcium concentrations do not vary appreciably anywhere in the groundwater flow system (see Figures 9 and 14).

Figure 15 shows the bicarbonate concentrations over the same period. Bicarbonate is a non-hazardous constituent that serves as the primary indicator of seepage impact in the Southwest Alluvium. Wells EPA 25 and 509 D previously showed post-shutoff uptrends in bicarbonate. Bicarbonate concentrations in 509 D have stabilized since 2011. The other wells have, at different times, achieved post-shutoff stability. These observations indicate that neutralization and geochemical attenuation have been occurring naturally, and that alluvial mineral salts dissolve into the alluvium groundwater. We conclude that most of the system has largely attained a new steady-state with respect to bicarbonate following the termination of alluvial groundwater extraction.

Sulfate and TDS

Sulfate and TDS are non-hazardous constituents that are not regulated by NRC. They do not have federal drinking water MCLs; they do have SMCLs. As shown on Figure 9 (and consistent with Zone 1 and Zone 3), most of the TDS is comprised of sulfate. The revised EPA cleanup standards (5,815 mg/L for sulfate and 10,376 mg/L for TDS), which account for background geochemistry, eliminate most of the Site's historical sulfate and TDS exceedances.

Figure 16 shows sulfate concentrations from 1999 through October 2018 and Figure 17 presents TDS concentrations over the same period. Sulfate concentrations exceed the revised EPA cleanup standards in the Southwest Alluvium only in non-seepage-impacted Well SBL 1. TDS concentrations do not exceed the revised EPA cleanup standard in any well in the Southwest Alluvium. Concentrations of sulfate and TDS are typically lower within seepage-impacted waters than within non-seepage-impacted Well SBL 1, and they are not expected to rise above the values measured in SBL 1.

Chloride

The EPA cleanup standard (250 mg/L) for chloride derives from the New Mexico Water Quality Act, which is also the federal SMCL (this constituent does not have a federal primary MCL). Figure 12 presents chloride concentrations from 1999 through October 2018. Well 509 D is the only location where chloride concentrations have persistently exceeded the standard. Less common, and typically minor, exceedances have occurred in the past at Wells 632, 801, 802, GW 1, and GW 2.

Figure 12 shows that during the 18 months after the pumping shutoff, there were small Site-wide increases in chloride, after which concentrations returned to their pre-shutoff levels. The small increases may have been (at least partially) an artifact of the more frequent, monthly water quality measurements that were made for the 18 months following shutoff (after which the frequency returned to quarterly monitoring). Pumping had no effect on chloride concentrations with the apparent exception of Well GW 1, where post-shutoff increases stabilized in January 2004 at concentrations that occasionally show very small exceedances.

Manganese

Manganese is a non-hazardous constituent in water that is not regulated by NRC. It does not have a federal drinking water MCL; it does have an SMCL. The revised EPA cleanup level (2.1 mg/L) is lower than the historical EPA standard (2.6 mg/L) which was cited as background water quality in the ROD (EPA, 1988b).

Figure 11 presents manganese concentrations from 1999 through October 2018. Manganese is the only metal that consistently exceeds its revised EPA cleanup standard in seepage-impacted areas; however, there are no exceedances in seepage-impacted water outside Section 2. Exceedances occurred at six seepage-impacted wells: 801, 803, 808, 632, EPA 23, and 509 D during 2018. Concentrations at Well 0808 showed an increasing trend in 2018, peaking at 2.33 mg/L in October. Concentrations at Well 801 showed an increasing trend since a recent low in January 2012 (3.62 mg/L) to a peak in July 2014 (7.00 mg/L) but have since fluctuated and remain lower than concentrations observed prior to shutdown. Concentrations at Well 803 have fluctuated within a range of 2.15 to 3.55 mg/L, since 2012. The concentration trends have been relatively flat at Wells EPA 23, 632, and 509 D since 2000Well 509 D is an upgradient well that was not hydraulically influenced by the former downgradient extraction well pumping, and the changes of manganese concentrations are probably unrelated to previous pumping (the changes are slight, and concentrations appear to be stable between ~2 to ~4 mg/L. Wells 632 and 803 had manganese exceedances in samples from all four events in 2018. Manganese also exceeds the standard in background Well SBL 1. Monitoring well 802, located in the center of the seepage-impacted area, continued to show low manganese concentrations during October 2018 that were below the standard.

Manganese is a common accessory element, and its concentrations in water are tied to Eh-pH conditions rather than any association with the tailings seepage. It is expected that manganese concentrations will continue to be below the standard in most of the seepage-impacted wells outside Section 2 due to natural redox conditions and/or saturation with respect to rhodochrosite if bicarbonate concentrations are high enough; however, exceedances are expected to continue at Well EPA 23 and Well 509 D (both of these are POC wells located significant distances upgradient of the Section 2 property boundary), and Well 801. Based on long-term trends, slight exceedances may continue at Well 632 (also a POC well) and at Wells 803 and 808. In addition, manganese is expected to exceed the standard in background Well SBL 1.

Uranium

The statistical analysis included in the NA report (Earth Tech, 2002b) determined that there was not a significant increase in trend for uranium; however, the graphs of uranium concentration in several wells indicated a possible increase prior to, and during, the NA test. For this reason, UNC has continued to reassess the uranium trends as part of the Site annual reporting. GE has evaluated the regulatory significance of the occurrence and distribution of dissolved uranium in the Southwest Alluvium. That report (GE, 2006) was prepared to assist EPA in deliberations about applying the current MCL for uranium (0.03 mg/L) as a formal cleanup criterion in the Southwest Alluvium. Figures 18 through 34 (discussed below) show that uranium concentrations exceeding 0.03 mg/L have been reported for both seepage-impacted and background wells; currently, uranium concentrations in the three background wells (Wells SBL 1, 627 and EPA 28) are below 0.03 mg/L. The NRC standard for uranium is 0.3 mg/L; based upon the Site history and distribution of uranium in background and seepage-impacted water. This has been considered the most supportable uranium standard for this Site (GE, 2006); there was no proposed change in the 2012

License amendment request for revised groundwater protection standards based on updated background concentrations (BTVs) (UNC, 2012), and no change to the standard in the License amendment (NRC, 2015).

EPA and NMED provided comments on an NRC draft EA related to UNC's 2012 License amendment request. EPA and NMED concluded that they do not support the current License standard for uranium in the Southwest Alluvium (0.3 mg/l) but, instead, support the BTV calculated for uranium based on the UPL95 statistical methodology (0.205 mg/l). The UPL95-based BTV is inappropriate for the following reasons:

- The source of uranium in both background and seepage-impacted water in the Southwest Alluvium is not tailings seepage, but mine water, permitted in the case of the NECR mine to contain uranium concentrations up to 2 mg/l, discharged to Pipeline Arroyo from both the NECR and Quivira mines for 17 years. Mine dewatering operations discharged approximately 3,000 gpm of groundwater pumped from the mine permit areas within the Morrison Formation to Pipeline Arroyo from 1969 to 1986. A portion of the groundwater discharged to Pipeline Arroyo infiltrated into the Southwest Alluvium and uranium adsorbed or precipitated within the alluvial sediments and has naturally attenuated to concentrations far below the discharge permit limit of 2 mg/L.
- Uranium concentrations in the Southwest Alluvium attenuate via adsorption and/or precipitation such that background uranium concentrations decrease with increasing distances downstream and away from the arroyo centerline. This geochemical evolution of background (post-mining/pre-tailings) water causes the background concentration for uranium to be spatially and temporally dependent. Put another way, the statistical analysis of uranium background does not distinguish the spatial and temporal variance, and instead, calculates a biased value across all sample locations and times because most background samples were from downgradient locations where background uranium concentrations are biased low.
- The concentration of dissolved uranium in seepage-impacted water is often a function of the bicarbonate concentration, and uranium concentrations have been empirically found to lie within the same concentration range as the background (post-mining/pre-tailings) water. For example, the maximum Southwest Alluvium background uranium concentration used in the calculation of site background statistics (N.A. Water Systems, 2008b) was 0.367 mg/l, which exceeds the current NRC license standard. The net result is that uranium concentrations in seepage-impacted water may attain levels that are equivalent to the background water quality but not typically greater.
- Historically, there have been only occasional exceedances of the NRC License standard (0.3 mg/L) in the current Southwest Alluvium performance monitoring wells, most of which occurred at Well GW 3, and several of which occurred in Well 509 D (see Appendix A).
- A comprehensive review of historical uranium concentrations demonstrates that most of the seepage-impacted wells have shown overall stable to decreasing trends since the Southwest Alluvium extraction system was shut off in January 2001. The EPA (2013) acknowledged that "With the exception of POC Wells GW-3 and 509D, and the very slight increasing trend in non-POC Well EPA 25; uranium concentrations trends over the duration of monitoring have either stabilized or shown decreasing levels since the pumps were turned off." Uranium concentrations in samples from GW 3 continued to increase through

its last sampling in 2015 (discussion in following bullet), but uranium concentrations at Wells 509D and EPA 25 appear to have stabilized.

- There is only one monitoring location outside Section 2 (GW 3, just over the Section 2 boundary) where uranium concentrations have exceeded the NRC License standard (0.3 mg/l) and the BTV (0.205 mg/l) since the extraction wells were shut down. Uranium concentrations at this location are not representative of general conditions in the Southwest Alluvium because the water level is very low (beneath the 2-ft minimum specified in the sampling procedure) such that the well no longer provides representative samples. The BTV does not fully take into account differences due to well construction and effects of decreasing saturated thickness. For example, as the saturated thickness declines (as in well GW 3), the well may become isolated or hydraulically disconnected from the Southwest Alluvial flow system; groundwater under these conditions is not representative of typical groundwater quality because it has greater opportunity to geochemically evolve and reach local equilibrium with the formation. This is further supported by the fact that there are no Southwest Alluvium monitoring wells between GW 3 and the tailings impoundment that have uranium concentrations exceeding the NRC License Standard or having increasing trends.

- The background water exhibits the same overall range in uranium concentrations as in the seepage-impacted water, but the timing and location of a particular uranium concentration depends more upon its particular flow path than on its origin as either post-mining/pre-tailings water (i.e. background) or tailings seepage.

Consequently, UNC has recommended that the uranium standard in the Southwest Alluvium be waived (Chester Engineers, 2015b) and there is no reference to the EPA cleanup level indicated on Table 2 or the historical data table in Appendix A.

Graphs of uranium concentrations in Southwest Alluvium water-quality performance monitoring locations (including SBL 1), through October 2018, are included as multi-well plots in Figures 18 and 19. Figure 18 shows only the seven POC wells; Figure 19 shows other selected wells, including background wells. Graphs of uranium concentrations are shown separately for each well in Figures 20 through 34:

- Well 509 D (Figure 20): The uranium concentration in Well 509 D, which is located upgradient of the South Cell and the other Southwest Alluvium wells, increased for one full year prior to the NA test starting in October 1999 (pumps were shut off in January 2001). Relatively large fluctuations have been characteristic since shutoff and during earlier periods. The concentration trend had been overall stable (i.e., approximately horizontal on the chart), at the higher end of the historical range, from July 2000 through October 2008, when an increasing trend started. However, since 2014 the concentration trend may have stabilized and reversed. Well 509 D is located outside the zone of influence of the former pumping wells; it is not a good indicator of whether there is a benefit to pumping. Furthermore, based on the saturated thickness map (Figure 3B), Well 509D appears to have limited connection to the Southwest Alluvium flow system; this relative isolation may be a reason for differing geochemical responses than those observed downgradient.

- Well 801 (Figure 21): The uranium concentration in Well 801 increased to its maximum just prior to shutdown and decreased through most of the NA test. The concentrations decreased and stabilized, approaching the long-term average concentration that had been extant during pumping. The 800-series wells are also closest to the tailings impoundment, and as such, would be expected to reveal any anomalous uranium concentrations that originate from the tailings impoundment seepage. No anomalies are present which suggests that the tailings seepage is not the source of uranium in the Southwest Alluvium.

- Well 802 (Figure 22): Well 802 was a pumping well that was shut down on January 8, 2001. Subsequent concentrations increased through September 2001, were stable through October 2003, then decreased overall and have been stable since 2008.

- Well 803 (Figure 23): The uranium concentration in Well 803 spiked in the year 2000, more than one year before the NA test. Only one of the samples collected since shutdown showed a higher uranium concentration than the two relatively high concentrations that were measured during 2000, before the shutdown. Post-shutoff concentrations increased through July 2002 to a similar value to those measured pre-shutoff during May and July 2000. Since July 2002, the trend has been decreasing and concentrations are consistent with the historical range (also see Appendix A, Table A.1). This is an example showing that although heterogeneous uranium-bearing waters may pass through the system, they will tend to approach a stable, average concentration whether or not the pumps are running.

- Well GW 1 (Figure 24): The uranium concentrations in Well GW 1 began to increase in 1999, well before the NA test, and therefore cannot be attributed to the cessation of pumping. Post-shutoff concentrations continued to increase at an accelerated rate through July 2002 and then decreased through January 2004, at which time they stabilized. Figure 24 shows that uranium and bicarbonate concentrations have had over time a history of covariance at GW-1.

- Well GW 2 (Figure 25): Post-shutoff uranium concentrations were stable through October 2002; then they increased to October 2005, after which they have defined an overall decreasing trend. Uranium concentrations after the shutdown of pumping have been within the historical range of those before the shutdown. Furthermore, uranium concentrations between shutdown and October 2002 were similar to concentrations prior to the cessation of pumping, indicating that subsequent fluctuations were unrelated to the shutdown. Well GW 2 has not been sampled since July 2015 and can no longer be safely sampled due to its proximity to the unstable edge of Pipeline Arroyo canyon.

- Well GW 3 (Figure 26): Since shutoff, the concentrations increased from 0.059 mg/L in February 2001 to 0.423 mg/L when it was last sampled in July 2015, defining a linear rate of increase of +0.025 mg/L per year over this period of 14.7 years. GW 3 is the only Southwest Alluvium well to show a persistent increase in uranium since shutoff. However, this does not necessarily indicate a causal relationship between the increasing trend and shutoff. For example, nearby Wells GW 1 and GW 2 have exhibited different concentration changes over the same time-frame. It is not clear what physical or chemical mechanism stemming from the shutoff could account for changes so heterogeneous in degree and timing over a relatively small downgradient area. Uranium concentrations in many Southwest Alluvium wells have shown that variously gradual to steep uptrends and downtrends are typical, whether they occur during pumping or in the absence of pumping. In previous annual reports it was observed that starting in approximately January 2008, there has been little to no covariance between the bicarbonate and uranium concentrations, an interpretation likely affected by periodic fluctuations in the bicarbonate concentrations. However, with the inclusion of the 2013 through 2015 data, Figure 26 demonstrates uranium and bicarbonate covariance since July 2009 in that both have followed increasing trends:

uranium increased from 0.125 mg/L (July 2009) to 0.423 mg/L (July 2015) and bicarbonate increased from 1,410 mg/L (July 2009) to 1,670 mg/L (July 2015). Hydrologic conditions may also influence uranium concentrations at GW 3. This well had a very short water column (when last measured in July 2015 at 2.07 ft, or 4 percent saturated thickness) at the edge of the saturated zone in the Southwest Alluvium and the piezometric surface was projected to be below the base of the alluvium in 2018. By comparison, in October 2003 the water column here was 7.52 ft tall (representing 13% saturated thickness). The declining saturated thickness observed near Well GW 3 may have contributed to the elevated uranium concentrations (i.e., consistent with the hypothesis developed by NRC (1996)). Furthermore, at these low saturated thicknesses, Well GW 3 did not produce sufficient volume for sampling using low-flow sampling protocols such that it had to be sampled on the next day to acquire the necessary sample volume. As the saturated thickness declined, the well is interpreted to have become isolated or hydraulically disconnected from the Southwest Alluvial flow system; samples collected under these conditions are not representative because the groundwater has had greater opportunity to geochemically evolve and reach local equilibrium with the formation. Well GW 3 can no longer be safely sampled due to its proximity to the unstable edge of Pipeline Arroyo canyon.

- Well 624 (Figure 27): Post-shutoff concentrations have been stable at the lower end of the historical range. This chart also shows the bicarbonate time series at this well. Unlike the periods of covariance between uranium and bicarbonate shown in Wells GW 1 (through April 2002) and EPA 25, Well 624 conspicuously lacks covariance. This observation is discussed later in this section.

- Well 632 (Figure 28): Post-shutoff concentrations have been stable at the lower end of the historical range (excluding a drop to nondetect in April 2004).

- Well 627 (Figure 29): Post-shutoff concentrations have been stable at the lower end of the historical range.

- Well 808 (Figure 30): This well was installed in conjunction with the planned shutoff of the extraction well system; it has no pre-shutoff history. The post-shutoff uranium concentration showed a large upward spike through September 2001; since then the trend was strongly downward through October 2002, subsequent to which the concentrations have stabilized and show a decreasing trend.

- Well EPA 23 (Figure 31): Post-shutoff concentrations have been stable at the lower end of the historical low range.

- Well EPA 25 (Figure 32): Uranium concentrations were stable from July 1999 to January 2007, after which covariant increases of uranium and bicarbonate concentrations are observed. This chart also shows that the covariance of uranium and bicarbonate concentrations occurred over most of the history of monitoring. The onset of seepage impact at this well occurred during October 1995. An upward step in bicarbonate concentrations started in April 2006, while an apparent upward step in uranium concentrations started slightly later in January 2007. These geochemical changes occurred many years after the shutoff of the pumps. EPA 25 uranium concentrations appear to have stabilized over approximately the past four years at levels substantially lower than the NRC standard (October 2018, 0.126 mg/L). This uranium-bicarbonate relationship can be explained by the basic geochemical principles presented by GE (2006). EPA 25 is along the northwest flank of the bicarbonate impact area (see Figure 8).

- Well EPA 28 (Figure 33): Concentrations were quite stable from July 1989 until 2014 when concentrations decreased from 0.0526 mg/L in March 2014 to restabilize around 0.020 mg/L since January 2016. The concentration in October 2018 was 0.0189 mg/L. This decrease corresponds with a decrease in bicarbonate concentration observed during the same period (Figures 13 and 15).
- Well SBL 1 (Figure 34): Concentrations at this newest, downgradient background well have varied from 0.0066 mg/L to 0.0332 mg/L.

This comprehensive review of historical uranium concentrations demonstrates that most of the seepage-impacted wells have shown overall stable to decreasing trends since shutoff. Exceedances of the Site License standard for uranium have been limited to one in Well 509 D during October 2010 and twelve in Well GW 3 (all between October 2012 and July 2015). All the other wells have shown post-shutoff concentrations within their pre-shutdown historical ranges, and many of the wells show that both gradual and sudden variations are common. The GW 3 uranium exceedances appear to be isolated spatially and analytical results since July 2009 indicate the covariance of uranium with bicarbonate concentrations. The short water column at this location may also have affected observed uranium concentrations. Uranium concentrations in many Southwest Alluvium wells have shown that variously gradual to steep uptrends and downtrends are typical, whether they occur during pumping or in the absence of pumping. UNC concludes that pumping would not result in a general Southwest-Alluvium-wide improvement in groundwater quality with respect to uranium or any other constituent.

EPA (2008) has stated (p. 53, Issue # 4):

"If the source of the uranium is the alluvial sediment, the increase in bicarbonate levels, as believed to be controlled by the shutoff, would be expected to influence the distribution and concentration of uranium. The bicarbonate levels are believed to determine whether or not the non-tailings-sourced uranium is dissolved, precipitated, or adsorbed. Thus, if the bicarbonate continues to migrate, then any uranium which could be sourced from the alluvium is expected to mimic the bicarbonate and migrate accordingly. In light of this, there remain questions regarding the effectiveness of the extraction wells to improve ground-water quality with respect to uranium."

EPA (2008) indicated that this and related statements in their third Five-Year Review report derived from their review of the 2007 Annual Review Report (N.A. Water Systems, 2008a) and the evaluation of the regulatory significance of the occurrence and distribution of dissolved uranium in the Southwest Alluvium (GE, 2006). UNC concurs that degrees of covariance between bicarbonate and uranium groundwater concentrations have been demonstrated in many Southwest Alluvium wells, and that the alkalinity of seepage-impacted water can be a strong determinant of how much uranium will be partitioned between the aqueous and (a typically surface-bound) solid phase (GE, 2006). UNC also believes that the weight of empirical evidence demonstrates that re-starting groundwater extraction will not improve groundwater quality in the Southwest Alluvium.

Uranium concentrations attenuate via adsorption and/or precipitation such that background uranium concentrations decrease with increasing distances downstream and away from the arroyo centerline; this likely heterogeneity of the uranium distribution (of non-tailings origin) within the Southwest Alluvium sediments may inherently limit one's ability to predict the degree (or even presence) of such covariance. For example, the increase in bicarbonate to a plateau at Well 624

(Figure 27) starting in May 2000 is attributed to the migration of the bicarbonate "front" associated with tailings seepage-impact. However, this well shows no covariance between the bicarbonate and uranium concentrations. At least two interpretations are possible: (1) at this well location there is little to no adsorbed or precipitated uranium (i.e., solid phase) within the alluvial sediments; and (2) aqueous uranium that originated from upgradient tailings seepage impact has been strongly attenuated during transport and has not reached this location.

Excluding the sharp and singular increase in Well 509 D during October 2010 and 2012 to 2015 results in Well GW 3, the Southwest Alluvium wells have not shown exceedances of the Site License uranium standard (0.3 mg/L). The time-concentration plots indicate that natural attenuation, by neutralization and adsorption, is at least equally as effective as a pumping remedy. This conclusion is bolstered by earlier discussion indicating that in comparison to background water quality, the passage of the seepage-impact front presages an improvement in sulfate and TDS concentrations. However, the data also demonstrate that the interaction of the uranium in the Southwest Alluvium sediments with varying geochemical (e.g., bicarbonate) or hydrologic factors (e.g., reductions in saturated thickness, isolation from the groundwater flow system, or geochemical interaction with the underlying bedrock) may result in variable concentration trends accompanied by localized exceedances of the current Site uranium standard (0.3 mg/l). The uranium standard in the Southwest Alluvium should be waived because the principal source of uranium for both background and seepage-impacted waters was the permitted mine discharge water rather than tailings seepage. It also is not possible to ensure that a standard will be achieved consistently throughout the seepage-impacted area as the geochemistry fluctuates and water levels decline over time. Moreover, the standard will only be attained upon extraction of all water in the alluvium, which is not practicable.

Pb-210

There was one Pb-210 detection in 2018 Southwest Alluvium samples (Well 801 at 6.8 pCi/L in April 2018); this result exceeds the NRC license standard (and revised EPA standard) of 5.9 pCi/L. This is the first exceedance of the Pb-210 standard at Well 801 since 1997. The Pb-210 activity was non-detect in the other three samples collected from Well 801 in 2018, which included two samples taken subsequent to the April sample.

SECTION 3
ZONE 3

3.1 CORRECTIVE ACTION SUMMARY

3.1.1 Northeast Pump-Back and Stage I and II Remedial Action Systems

The historical corrective action in Zone 3 consisted of pumping the three sets of extraction wells shown on Figure 35: (1) Northeast Pump-Back System (green triangles), (2) Stage I Remedial Action System (empty black squares), and (3) Stage II Remedial Action System (filled blue squares). The Northeast Pump-Back wells started operation in 1983; the Stage I and II wells were added later as part of the Remedial Action Plan (UNC, 1989b) implemented in 1989. While operating, the corrective action system in Zone 3 performed as designed to enhance dewatering of the seepage-impacted area and remove constituent mass.

The numbers of operating extraction wells were reduced as Zone 3 dewatering caused sustainable pumping rates to drop below 1 gpm. The number and pumped volumes of the former extraction wells, during the period of Zone 3 corrective action from 1989 through 2000, have been summarized in Earth Tech (2002c, Figure 3-2). Pumping from the last three of these extraction wells ceased in 2000. The NRC amended the License (with approval from NMED and EPA) to shut off the three remaining wells (716, 717, and 718) in December 2000. This decision included a provision for UNC to submit a modified corrective action plan, an application for ACLs, or an alternative to the specific requirements of 10 CFR Part 40, Appendix A, if the License standards are not achievable. With respect to the source materials license, the corrective action program in Zone 3 has undergone significant evaluation and evolution since the pumping was temporarily ceased over a decade ago. Notably, UNC conducted pilot programs involving hydraulic fracturing to improve well yields, and an alkalinity stabilization program to neutralize the acidic uranium mill tailings seepage. These efforts have been documented in several reports and correspondence and are also summarized in the Annual Reports that are required under Condition 30.C (including the current report).

3.1.2 2004 Supplemental Feasibility Study

At the request of the EPA (2004b), UNC conducted a Supplemental Feasibility Study (SFS) to evaluate all appropriate remedial options for Zone 3. Prior to reporting the SFS (MWH, 2004), UNC submitted (2004) a Technical Memorandum including a chronology of events that led to UNC's initiative to aggressively develop remedy modifications or enhancements that might improve the performance of the remedy in Zone 3. The SFS report presented (1) groundwater modeling of the Zone 3 sandstone unit and the locally overlying alluvium, (2) pilot-hole hydrofracturing study results, (3) a remedial alternatives analysis, and (4) conclusions and recommendations for enhancing or optimizing remedies for Zone 3.

Two studies were conducted based on recommendations of the SFS. These were an in-situ alkalinity stabilization pilot study and the pilot and Phase I hydrofracture program. These studies are described below.

3.1.3 In-Situ Alkalinity Stabilization Pilot Study

UNC conducted an in-situ alkalinity stabilization pilot study to evaluate the potential to enhance the ongoing Zone 3 remediation through the use of alkalinity injection wells combined with carefully controlled extraction pumping at the Site. The proposed approach for the pilot study was presented in the In-Situ Alkalinity Stabilization Pilot Study (BBL, 2006), which was approved by EPA.

The pilot study was initially designed to test the injection of alkalinity-rich groundwater from a non-seepage-impacted part of the Southwest Alluvium into the Zone 3 aquifer. The injected water (so-called “fixiviant”) would flow through the Zone 3 formation to recovery wells where the fixiviant could be pumped to the surface for treatment and disposal. However, NMED expressed concerns that the groundwater from the Southwest Alluvium did not meet applicable groundwater standards for sulfate, TDS, and manganese. The pilot study approach was revised to include injection of water withdrawn from the Westwater Canyon Formation via the Mill Well (amended with sodium bicarbonate to add alkalinity) into Zone 3(BBL, 2006).

The pilot study was conducted from October 24, 2006, to February 15, 2007. The observed injection and extraction rates were unexpectedly low. As a result, the estimated travel time between the injection and extraction wells became prohibitively low and the pilot test was terminated. The pilot study results indicated that the mineral feldspar in the Zone 3 arkosic sandstone had been altered by the acidic tailings liquids, generating kaolinitic clay that clogged pore spaces and significantly reduced hydraulic conductivity. Under these conditions it would take 10 times longer to accomplish remedy goals than had been hypothesized; a remedy enhancement anticipated to take approximately 5 years could actually take 50 years or more. Based on these results, it was concluded that the use of alkalinity rich solutions to remediate the Zone 3 seepage-impacted groundwater in-situ was infeasible (ARCADIS BBL, 2007).

3.1.4 Phase I Hydrofracture Program and Continuing Zone 3 Extraction Well Pumping

Seepage-impacted groundwater extraction from a new array of wells (identified as RW-series wells in the northern part of Zone 3 in Section 36 [see Figure 36 and Figure B-1 in Appendix B]) was tested in April 2005 as part of the Phase I (i.e., post-pilot) hydrofracture program (MACTEC, 2006). Continuous pumping of Wells RW 11, RW 12, RW 13, RW 15, RW 16, and RW 17 began in May 2005 (RW 14 was located in an area with less than one foot of saturation in Zone 3 and was not used as an extraction well). The new pumping array initially had three beneficial effects:

- Capture of most, if not all, of the northward-advancing seepage-impacted water (i.e., partial hydrodynamic control);
- Marked groundwater quality improvement and recession of the seepage-impact front to the south; and
- Dewatering and mass removal.

However, the groundwater quality improvement was temporary due to declining pumping rates and several extraction system modifications were subsequently made. Well PB 2 was converted to an extraction well in November 2005 to complement the RW-series pumping wells in the northern area of the seepage-impacted water. Pumping from recovery Well RW A was started during September 2007 at a location recommended by MACTEC (2006) to augment hydraulic containment (see their Figure 3.11). Extraction Wells PB 2, RW 12, RW 13, and RW 15 were later idled, due to fouling and/or insufficient yield.

Five new extraction wells (NW 1 through NW 5) were sited based on a UNC analysis (N.A. Water Systems, 2008c) and installed during September 2008 to intercept and recover seepage-impacted water. These well locations are shown on Figure 35 and Figure B-1 (Appendix B). All five wells were tested for a short period beginning in February 2009 to determine that they were pumping properly; pumping ceased at NW 4 and NW 5 in March 2009 and continued at Wells NW 1, NW 2, and NW 3. During November 2009, NW 3 was shut down to minimize the potential of drawing seepage-impacted groundwater to the northwest and pumping was initiated at NW 4. Yields subsequently declined and pumping was suspended at NW 1 in May 2012 and at NW 4 on October 21, 2015. Pumping was initiated at NW 5 on March 16, 2016 as a replacement for NW 4. The current pumping rates at NW 2 and NW 5 averaged approximately 0.16 gpm and 0.25 gpm, respectively, during 2018. NW 2 is reportedly reaching the end of its capability as a pumping well as pore spaces are clogged by fine clays and flow to the well has been reduced.

The Zone 3 corrective action system during 2018 comprised extraction from Wells RW 11, RW 16, RW 17, RW A, NW 2, and NW 5. Approximately 19,004,147 gallons of groundwater have been pumped from this new Zone 3 extraction well network from January 2005 through the end of November 2018 and piped to the evaporation pond.

3.1.5 Evaluation of the Effects and Limitations of Zone 3 Extraction Well Pumping

Twenty-nine years of remedial pumping have resulted in significant dewatering of Zone 3. One effect of this is that once the saturated thickness falls to approximately 25 ft or less, well efficiency declines and pumping rates fall to less than 1.0 gpm (Earth Tech, 2001). Appendix A of the ROD (EPA, 1988b) anticipated that these "significant declines in pumping rates with time due to insufficient natural recharge of aquifers" will occur and that "In the event that saturated thicknesses cease to support pumping, remedial activity would be discontinued or adjusted to appropriate levels."

Table 7 presents the reductions in saturated thickness for Zone 3 monitoring wells between the third quarter of 1989 and the fourth quarter of 2018. In previous versions of this table, values of saturated thickness greater than 25 ft were shaded. Beginning in 2012, none of the monitored Zone 3 wells met this criterion. For the 2013 Annual Report, adjustments were made to the saturated thickness calculations for Wells EPA 14 and NBL 1 as well as PB 2, PB 3, and PB 4 (not included on Table 7) after review of well information. The corrections yielded net decreases in the saturated thickness at Well EPA 14 (1.73 ft) and PB 4 (10 ft) and net increases in the saturated thickness at NBL 1 (4 ft), PB 2 (2.4 feet) and PB 3 (approximately 2 ft).

The saturated thickness measured in Zone 3 wells has declined by approximately 80 percent on average since the third quarter of 1989. Figure 35 shows that between 1989 and the fourth quarter of 2018, a very large portion of the Zone 3 Remedial Action Target Area has been desaturated (effectively dewatered). The eastern limit of Zone 3 saturation has shifted to the west-northwest over this time period (from the location of the wavy blue line, showing the saturation limit in 1989, to the dashed brown line showing the approximate October 2017 "zero" saturation limit). Figure 37 shows the overall dewatering effects of both the former and the current Zone 3 remediation pumping. The figure identifies the start of recovery pumping from the well array installed during the hydrofracture study in April 2005. Zone 3 water levels are demonstrated to be declining with time at all wells, except Well 446, which has shown an overall slightly increasing trend with small fluctuations between July 2010 and October 2018. However, Well 446 water level measurements are no longer valid; the water level is below the bottom of the screened interval (there is a 10-ft section of blank well casing below the well screen) and it is difficult to measure due to the presence of a floating natural oil lens. Therefore, the Well 446 water level value used for the potentiometric surface map and saturated thickness map has been estimated based on the surrounding wells and an extrapolation of the decreasing water level trend before the water level dropped below the screened interval. Additionally, the Well 420 water level dropped below the screened interval and the base of Zone 3 beginning with the April 2017 measurement (water levels were possible because a 5-ft section of blank well casing extends below the well screen). Measured values are not representative of Zone 3 and are therefore no longer valid. Monitoring wells that do not meet monitoring objectives are considered candidates for decommissioning, which may be recommended to NRC in a revision to the pending License amendment request or in a future License amendment request.

The main reason that the groundwater flows toward the north is that the Zone 3 bedrock unit dips toward the north. The hydraulic head that drives the flow comprises two components: the elevation head plus the pressure head. The long history of extraction pumping in Zone 3 has reduced the pressure head component of the total hydraulic head. However, it is not possible to reduce the slope-related elevation head – that is a driving force component that cannot be changed (N.A. Water Systems, 2008b). Continued pumping has been helping in the short-term as Figure 37 shows; however, the Zone 3 saturated thicknesses are quite shallow and eventually there will be no further possible reduction in the pressure head. The effort to counteract the overall hydraulic head is gradually approaching practical limits as the well yields decrease. The seepage-induced permeability reductions caused by the alteration of feldspathic minerals (see Section 3.1.3) will ultimately retard further northward migration of seepage-impacted water. The exact timing and location of the development of this critical balance cannot be predicted – but such a condition should inevitably occur.

The inherent difficulty of pumping seepage-impacted water in northern Zone 3 is demonstrated by the small groundwater flux. N.A. Water Systems (2008c) calculated that the groundwater flux (without any pumping) along a 1,200-ft long, west-northwest trending line of cross section located between Wells NBL 1 and PB 3 was 512 ft3/day (2.7 gpm) during January 2005, which is equivalent to the discharge from a home garden hose turned on low. This flux estimate has decreased as a result of the ongoing reduction of saturated thickness.

The revised Zone 3 pumping system has been declining in performance and active remedial operations in Zone 3 are reaching the limits of their effectiveness as anticipated by Appendix A of the ROD (EPA, 1988b) and acknowledged in EPA Five-Year Review reports (e.g., EPA, 1998; EPA, 2008; EPA, 2013; EPA, 2018). All of the Zone 3 wells have reduced average yields that are below 0.3 gpm and pumping at Wells NW 1, NW 4, and PB 2 has been suspended in recent years due to low yield and insufficient water pressure. The following physical factors have controlled these declining yields:

- Encrustation along the wellbore of iron oxyhydroxides, carbonates, and/or gypsum;
- Precipitation of amorphous aluminosilicates (e.g., EPA 14);
- Alteration of feldspar to clays within the bedrock matrix; and
- Reduced saturated thicknesses.

Pumping was initiated at NW 5 on March 16, 2016, as a replacement for NW 4 (shut down in October 2015) at a pumping rate of approximately 0.5 gpm (currently averages approximately 0.25 gpm). This pumping is intended to slow the potential migration of seepage-impacted water north of the Section 36 boundary. However, the operation of NW 5 has resulted in a slight northwestward shift in the mapped areal extent of seepage-impacted water relative to the extent depicted for October 2015, but the same as depicted for October 2016 and 2017 (see Section 3.3.2 and Figure 35). The combined time-averaged extraction rate of the six currently pumping wells in northern Zone 3 in the 2018 monitoring period (December 2017 through November 2018) was approximately 1 gpm, which constitutes approximately 41 percent of the 2.7 gpm total flux calculated in January 2005. UNC personnel report some concerns about the reliability of the extraction well flowmeter data as the saturated thickness declines, due to both the low flow rates/volumes and the presence of suspended clays that coat the flowmeter components and periodically render them inoperable. UNC will continue to evaluate flow monitoring methods in the future as needed. While acknowledging these potential metering limitations, the efficiency of seepage-impacted water removal has declined with time and decreasing saturated thickness and is expected to continue to degrade. Seepage removal efficiency will be considered in the SWSFS as the means to evaluate the effectiveness of any proposed remedy alternatives utilizing pumping wells.

Groundwater quality in northern Zone 3 has been shown to have oscillated between degrading and improving trends (see Section 3.3.2 and Chester Engineers, 2015a). The variations in water quality indicate that there have been local and variable degrees of mixing of seepage-impacted water with background water drawn in from the west and north. Consistent with UNC's original recommendations (N.A. Water Systems, 2008c) and a later update (Chester Engineers, 2009c), UNC has adjusted the pumping regime among the NW-series wells as needed to attempt to: (1) limit the withdrawal of background water; (2) limit the tendency for seepage-impacted water to be drawn westward or northward; and (3) improve the capture of seepage-impacted water. As always, the goal is to strike the best balance between containing the seepage-impacted water while minimizing its transport to the more thickly saturated but non-seepage-impacted parts of Zone 3.

UNC continues to evaluate the chemistry, water levels, and well yields in Zone 3, which may result in recommendations for further modifications to the extraction system operations (e.g., initiation of pumping from additional or different locations). Extraction wells having yields below the 1 gpm decommissioning criterion may be recommended to NRC for decommissioning in a revision to the pending License amendment request or in a future License amendment request. Extraction system operational data may also be considered with respect to remedy alternative evaluations performed in the SWSFS.

3.1.6 Injection Well Feasibility Testing and Pilot Study

Injection well feasibility testing, and its historical context, has been discussed in previous Annual Reports (e.g., Chester Engineers, 2010a; 2011a; and 2012b). The first injection testing was in background Well NBL 2 (Chester Engineers, 2009d). The second injection testing was in the pilot injection Well, IW A (Chester Engineers, 2010b).

On April 14, 2011, injection of water amended with sodium bicarbonate (2 grams per liter) started at Zone 3 Well IW A (Chester Engineers, 2011c). The objectives of the injection were to (1) locally buffer and geochemically stabilize the seepage-impacted water with alkalinity (sodium bicarbonate), (2) redirect the seepage-impacted water into the capture zones of the northernmost extraction wells, (3) extend the life of the extraction wells by arresting the drawdown, and (4) provide a hydraulic barrier to the northerly advance of seepage-impacted groundwater. The injection capacity at IW A declined over time. In late June 2012 the capacity had declined to ~ 0.2 gpm (288 gpd) and it became very difficult to meet the target injection water level. On June 29, 2012, the injection at IW A was terminated after a total of 426,363 gallons of water had been injected.

An additional important reason that the alkalinity injection pilot study was terminated was the reported increase in the uranium concentration at monitoring Well MW 6, from 0.082 mg/L in July 2011 to 0.321 mg/L in July 2012 (see Appendix B, Table B.1). GE (2012a) discussed two possible explanations for the uranium concentration increase: (1) The remedial system was drawing-in background water (post-mining/pre-tailings) which contains higher uranium concentrations than either the MCL or seepage-impacted water (N.A. Water Systems, 2008e, 2008f); and (2) the possible influence of the sodium bicarbonate ($NaHCO_3$) amended water that was injected at Well IW A. Some combination of both reasons likely explains the changes in the uranium concentration data, and because the relative contribution of each cause is unknown, it was prudent to permanently discontinue the injection of alkalinity-amended water. NRC concurred with the decision (Roy Blickwedel, GE, personal communication with Yolande Norman, NRC, October 2012).

3.2 MASS OF CHEMICAL CONSTITUENTS REMOVED

The mass of chemical constituents removed by extraction well pumping was calculated for the 12-year period from July 1989 through June 2000. These calculations were presented in the previous annual reviews, and the final summary is presented in the 2000 Annual Review (Earth Tech, 2000e).

As previously discussed, the current extraction well pumping phase originated with the hydrofracture program and comprises RW-series the NW-series extraction wells (Figure 36 and Figure B-1 in Appendix B). Table 8 shows the estimated mass removal by this pumping from December 2017 through November 2018 (the similar Table 8 in the 2017 Annual Report showed data through November 2017). The recovered masses were estimated by multiplying the volume of groundwater pumped by the estimated concentration of each constituent in the pumped water. The constituent concentrations were estimated from concentrations measured in groundwater samples taken from the extraction wells and nearby monitoring wells during October 2018 (with exceptions noted in Table footnotes).

Pumping volumes have decreased over time. Table 8 shows the estimated total volume of water extracted during the period from December 2017 through November 2018 was 519,948 gallons, which is approximately 16 percent less than that pumped from December 2016 through November 2017, 30 percent less than the volume extracted December 2015 through November 2016, and 42 percent less than the volume extracted from December 2014 to November 2015. Recognizing the potential metering limitations, the decreases demonstrate that pumping yields are well below the NRC decommissioning criteria and are having only marginal benefits, at best, as anticipated by Appendix A of the ROD (EPA, 1988b) and acknowledged in EPA Five-Year Review reports (e.g., EPA, 1998; EPA, 2008; EPA, 2013; EPA, 2018).

3.3 PERFORMANCE MONITORING EVALUATION

3.3.1 Water Level Evaluation

The water level monitoring component of the current Zone 3 performance monitoring program is summarized in Table 9 and comprises quarterly monitoring of water levels in 22 wells. Well NBL 1 is not a formal requirement of the performance monitoring program but was also monitored for water level until it was dewatered [see note on Table 9]). Supplemental water level measurements are made at additional monitoring locations on quarterly or annual basis to support reporting and remedy evaluation efforts. The saturated thickness has decreased at four of the water level performance monitoring locations (Wells 504 B, 446, NBL 1, and 420) such that they no longer provide adequate and/or representative data. Starting in January 2011, water levels in Well 504 B became too low to allow sampling and the well went dry in 2012. Water level measurements in Well 446 are no longer valid because the water level is below the bottom of the screened interval and it is difficult to measure due to the presence of a floating natural oil lens (see Section 3.1.5). Well NBL 1 is within an area of active recovery well pumping; should pumping be terminated it could again become relevant. As of April 2017, the water level in Well 420 was below the base of Zone 3 and the screened interval of the well. Although reported here, water level measurements and water samples collected during 2018 and the last three 2017 quarters at this location are considered not to be representative of Zone 3 (the water chemistry associated with Zone 2 [primarily shale and coal] would be expected to be dissimilar) and not valid. Well 420 may be influenced by active pumping of the RW-series wells, so it could also become relevant again if pumping were to be terminated. Monitoring wells that do not meet monitoring objectives are considered candidates for decommissioning, which may be recommended to NRC in a revision to the pending License amendment request or in a future License amendment request.

Water level data from 1989 through October 2018 are presented for sampled wells in Appendix B. Figure 36 shows the locations of extraction wells, monitoring wells, and the October 2018 potentiometric surface based on groundwater elevation measurements. This potentiometric map, which has a 5-ft contour interval, indicates that groundwater flows toward the north and northeast, approximately parallel with the eastern limit of Zone 3 saturation. Overall, the potentiometric field is similar to those depicted in recent annual reports. The water levels in the vicinity of Wells NW 2 and NW 5 are consistent with the convergence of groundwater flow lines toward these extraction wells. As observed in 2013 through 2017, water levels at certain northern Zone 3 wells have decreased significantly in response to pumping.

Groundwater discharge into Pipeline Arroyo, associated with historical mining operations, ceased in 1986. Since then, Zone 3 water levels have been declining and groundwater flow directions became more generally north-northeasterly as recharge from, and groundwater mounding within, the alluvium to the southwest and west has steadily decreased (Chester Engineers, 2012c, 2014b). The earlier east-to-northeast flow direction caused the distribution of groundwater impacts that was the original basis for delineation of the Zone 3 Remedial Action Target Area, as shown on Figure 35. Effects on the potentiometric surface from alluvium recharge (mine-dewatering groundwater discharge) have largely dissipated, and rates of water level change in Zone 3 are mostly very slow (excluding the influence of recent pumping). Pumping of extraction wells prior to January 2001 temporarily accelerated the local rates of water level decline until the saturated thickness was reduced to less than ~ 25 ft, after which the decline in levels slowed to natural rates of drainage. In October 2018, the collective average saturated thickness for all measured Zone 3 wells (Table 7) has reduced to approximately 9.3 ft.

Contours of saturated thickness during the October 2018 monitoring event (Figure 38) show the combined effects of former pumping, current pumping, the former injection program, and natural drainage on Zone 3. The values posted on Figure 38 are calculated saturated thickness values for wells that have a measured water level during the October 2018 monitoring event. The saturated thickness value posted for Well 420 is “Dry”, because the measured water level value is below the base of Zone 3. These posted values were not used to create the map contours; the contours were developed by subtracting one interpolated surface (the elevation of the base of Zone 3) from another (the potentiometric surface for the October 2018 monitoring event). The Zone 3 base surface is interpolated from historical well log data in the investigation area and the potentiometric surface is shown in Figure 36. There are a few small areas in the center of the seepage impacted area that are mapped as having zero saturation. These areas occur where the estimated potentiometric surface is equal to, or lower than, the mapped elevation of the Zone 3 base (many of these locations coincide with historical 400-series monitoring wells) and may reflect an undulating Zone 3 base surface. Before 2016, small areas of zero saturation in the center of the seepage impacted area were disregarded, but as water levels and saturated thickness decline, the areas have become larger, and having no data to the contrary, are deemed valid. Similarly, the October 2018 map shows a notable westward adjustment in the eastern zero saturation boundary near Wells 446 and RW-12 (originally made in the 2017 Annual Review report (Hatch Chester, 2017) that reflects an increasing importance of undulations of the Zone 3 base surface in this area. Overall, the eastern extent of saturation has contracted to the west, so that the current boundary of saturation is approximately where the 25-ft saturated thickness contour was located in 1989 (for comparison, see Earth Tech, 2002c, Figure 3-1).

Wells located to the west, closer to the former recharge area, also have lost substantial saturation. For example, Well EPA 14 had 76 ft of saturation in 1989 and 18.15 ft in October 2018 (a 76 percent reduction in the saturated thickness; see Table 7). Table 10 shows the saturated thickness in each Zone 3 well during October 2018. From 2002 through 2018, most wells have shown overall decreasing groundwater elevations (usually with small fluctuations), indicating that the Zone 3 potentiometric field that drives groundwater flow and constituent migration continues to become lower as the groundwater further drains away. Pumping has removed more than 19 million gallons from 2005 through November 2018.

The southwest part of Figure 35 shows the approximate contact area between the alluvium and the top of Zone 3. Former versions of this figure have shown an inferred area of saturation along this contact area (e.g., see Figure 35 in the 2008 Annual Report). N.A. Water Systems' (2008c) analysis of the groundwater flow through Zone 3 indicated little or no contribution from other sources (e.g., alluvium) than the ongoing self-drainage. There was very little flow crossing the southern, east-west directed cross section line near Well 613 (N.A. Water Systems, 2008c; Figure 7), which is 1,642 ft long: the flux here in January 2005 was estimated to be 723 gallons per day (0.5 gpm). Chester Engineers (2011d) summarized the lack of empirical evidence for discernible recharge into Zone 3. However, accounting for episodic recharge via streambed infiltration was found to benefit the calibration of the Site numerical flow model in the accuracy of its simulation of Zone 3 piezometric heads (Chester Engineers, 2012c, 2014b). Without such an accounting the model simulated a decline of the Zone 3 piezometric surface that exceeded that measured over the prior 12 years. The basis for this interpretation of Zone 3 recharge remains theoretical rather than empirical.

3.3.2 Water Quality Evaluation and Current Extent of Seepage-Impacted Water

Water Quality Evaluation

The temporary saturation caused by the infiltration of groundwater discharged into Pipeline Arroyo, during mining activities, is considered the background water for Zone 3 (EPA, 1988a; 1988b; 1998). This background water was later impacted by acidic seepage from tailings in the North Cell. These seepage fluids contained elevated concentrations of metals, radionuclides, and major ions including sulfate and chloride. Source control (neutralizing and later dewatering of the North Cell), neutralization of the seepage by natural attenuation, and mixing with the background water have reduced constituent concentrations.

Seepage-impacted water, some of which exceeds NRC License standards and/or EPA cleanup standards, is contained within the property boundary in Section 36. The portion of the Zone 3 seepage-impacted water that extends off the property into Section 1 (Figures 6 and 35) was eliminated as a point-of-exposure (POE) because of limited saturation. The decision to eliminate this area as a Zone 3 POE is documented in a letter from the NRC (1999b).

The current water quality monitoring component of the Zone 3 performance monitoring program is summarized in Table 9 and comprises quarterly sampling at 10 wells. The current monitoring program went into effect in the second quarter of 2000 and adjustments were subsequently made the request of the NRC. Well 504 B can no longer be sampled; in January 2011 water levels in 504 B became too low to allow sampling, and the well went dry in 2012. As of April 2017, the water level in Well 420 was below the base of Zone 3 and the screened interval of the well. Therefore, water level measurements and water samples collected since April 2017 at this location are considered not to be representative of Zone 3. Well NBL 1 (which is not included among the 10 wells on Table 9 because it is not currently identified as a monitoring point in the NRC License) was installed in 2001 to both bound the downgradient extent of the seepage-impacted water and function as a tracking well. UNC has submitted a License amendment request (GE, 2015), along with a subsequent amendment (GE, 2016b), to NRC that would formally add Well NBL 1 to the performance monitoring program. However, NBL 1 is within an area of active recovery well pumping and has not been sampled since January 2013 due to decreased water levels and sediment accumulation in the well. Should pumping be terminated in northern Zone 3, it could again become relevant as a monitoring point.

POC Well 517 does not meet performance criteria associated with low flow groundwater sampling methods, which limits the ability to collect representative samples. Drawdown measured at Well 517 during implementation of the low-flow sampling protocol exceeds the two-foot maximum drawdown specified in the SOP (Chester Engineers, 2015a). The protocol is intended to avoid increased flow velocities into the wellbore, which might increase sample turbidity and enhance local mobilization of constituents. This is contrary to the objective of low-flow sampling to measure naturally mobile constituent concentrations present in the formation outside the well. Well 719 also has a very low volume available for sampling and is considered to have “borderline” suitability for low-flow sampling methods (Chester Engineers, 2015a). Monitoring wells that do not meet operating criteria are considered candidates for decommissioning, which may be recommended to NRC in a revision to the pending License amendment request or in a future License amendment request.

The following groups of wells serve, or have previously served, as supplemental Zone 3 monitoring locations for field measurements and/or laboratory analyses:

- Northern tracking wells – The northern tracking wells have served to track the advance of the northernmost seepage-impact boundary and have historically comprised Wells 504B, NBL 1, the PB-series wells, recovery Well RW A, and Well NBL 2 (Figure 35). During 2018, the only northern tracking wells with sufficient saturated thickness for sample collection were Well NBL 2 and recovery Well RW A.

- Extraction Wells NW 1 through NW 5 – Extraction Wells NW 1 through NW were installed during September 2008 to intercept and recover seepage-impacted water (see well locations on Figure 35 and Figure B-1 [Appendix B]) and are used to track the advance of seepage-impacted water in northern Zone 3. Wells NW 2 and NW 5 were pumped during 2018. The historical pumping of these wells is described in Section 3.1.4. The current pumping rates at NW 2 and NW 5 each currently average approximately 0.15 to 0.25 gpm. This flow rate range is lower than that reported for the 2017 monitoring period (0.25 to

0.30 gpm) and well below the 1 gpm NRC decommissioning criterion. Well NW 2 is reportedly reaching the end of its capability as a pumping well as pore spaces are clogged by fine clays and flow to the well has been reduced.

- Wells MW 6 and MW 7 – Wells MW 6 and MW 7 were installed north of the seepage-impacted area in 2010 in association with the alkalinity injection pilot study (Figure 35).

The following summarizes the Zone 3 supplemental water quality monitoring that is not a formal requirement of the performance monitoring program:

- To improve the understanding of the groundwater quality along the northern front of the seepage-impacted water in Zone 3, the following additional wells were sampled during October 2018 for the full laboratory chemical parameter list: MW 7, NW 3, RW A, RW 11, and NBL 2 (see Appendix B). Samples are collected annually from Wells RW A, RW 11, and NBL 2 for the full parameter list. NW 3 has been sampled quarterly for the full parameter list since October 2016. MW 7 has been sampled for the full parameter list quarterly since July 2012 (with exceptions due to technical issues).

- Monthly measurements of select field parameters (pH, conductivity, chloride, and alkalinity [of which bicarbonate is the principal component]) continued during 2018 in the northern tracking wells (now limited to Wells RW A and NBL 2). Table 11 presents the historical monthly field parameter measurements for the northern tracking wells. Quarterly laboratory analytical results for these wells are provided in Appendix B.

- Monthly field parameter measurements were made at the five NW-series wells and MW 7 (Table 12). These measurements have been made in the NW-series wells since June 2009 and starting in August 2011 in Well MW 7. The monthly field parameter measurements have not been made for MW 6 since September 2015 due to decreased water levels.

- As a check of the monthly field parameters, quarterly samples were taken from several northern Zone 3 wells (RW A, NBL 2, NW 1, NW 2, NW 3, NW 4, NW 5, and MW 7) for laboratory analysis of bicarbonate, pH, TDS (in lieu of conductivity), and chloride (see Appendix B). Based on these comparisons, the field parameters were determined to provide a good indication of the migration of the seepage-impacted water.

- The following additional wells used historically for supplemental monitoring can no longer be sampled:

    - Well MW 6 was sampled for the full parameter list quarterly from July 2012 to April 2014 and for monthly field parameter measurements from August 2011 to September 2015. The measurements were discontinued due to decreased water levels and insufficient sample volume.

    - Well PB 2 was sampled at least annually during October since 2008 for the full laboratory parameter list but has not been sampled since July 2013 (pumping was discontinued).

    - Wells PB 3 and PB 4 were sampled annually in October from 2010 to 2014 for the full laboratory chemical parameter list but have not been sampled beginning in October 2014 due to insufficient sample volume. Beginning in October 2015, the monthly field parameter measurements have also no longer been made at PB 3 and PB 4 due to insufficient sample volume.

- Well NBL 1 was previously sampled quarterly but was last sampled in January 2013 due to decreased water levels and sediment accumulation in the well.

A summary of laboratory analytical detections for the Zone 3 monitoring locations in the October 2018 monitoring event is provided in Table 14. Historical groundwater quality and quarterly groundwater elevation data through October 2018 are provided in Appendix B (Table B.1). The site groundwater standards used for data comparisons in this annual report were revised through the development of updated BTVs by statistical analysis. NRC issued a License amendment to update site GWPSs (NRC, 2015) and EPA approved the use of the UNC proposed cleanup levels (EPA, 2015) for remedy alternative evaluation in the ongoing SWSFS.

The Zone 3 NRC POC Wells (517, 613, 708, and 711) are within the acidic "core" of the seepage-impacted water (Figure 35, in October 2018 all were below a pH value of 4.0 [the pH 3.0 contours have been omitted for figure clarity]). The following constituents exceeded NRC License standards at the POC wells during the 2018 quarterly monitoring (the numbers of exceedances are shown in parentheses):

- Well 517 – nickel (4).
- Well 613 – beryllium (4), nickel (4), vanadium (4), uranium (4), and thorium-230 (4).
- Well 708 – beryllium (4) and nickel (2).
- Well 711 –nickel (4).

NRC License standards were also exceeded at the following monitoring locations during 2018:

- Well 717 – beryllium, nickel, uranium, and gross alpha.
- Well NW 3 – arsenic and combined radium.

Additionally, EPA cleanup standards were exceeded at Zone 3 monitoring locations for beryllium, TDS, sulfate, aluminum, cobalt, and manganese during 2018. These are constituents that are not regulated by NRC, or for which the EPA cleanup standard is lower than the NRC License standard (i.e., beryllium). The analytical results are further discussed relative to the seepage impact extent in this section and relative to natural attenuation performance in Section 3.3.4. It is important to recognize that elevated analyte concentrations (including reported exceedances of historical NRC or EPA standards) in some Site wells represent background water quality. Background water quality is discussed further in the natural attenuation system performance evaluation (see Section 3.3.4).

Current Extent of Seepage-Impacted Water

Until groundwater discharges to Pipeline Arroyo ceased in 1986, seepage impacts in Zone 3 migrated to the east and northeast, due to groundwater mounding in the alluvium recharge area to the west. As the hydraulic head in the alluvium recharge area decreased (and with it the rate of recharge), migration shifted toward the north (in relatively southern locations) and northeast (in more northerly locations), subparallel to the eastern edge of saturation and the bedrock dip direction. Furthermore, as predicted in the EPA's First Five-Year Review Report (EPA, 1998) and discussed in the Technical Memorandum (GE, 2000), continued pumping of the downgradient Stage II extraction wells caused the seepage-impacted waters to migrate to the northwest and north toward the pumping locations.

The following criteria have been used to distinguish background versus seepage-impacted groundwater quality in Zone 3:

- pH < 5 and bicarbonate < 100 and > 500 mg/L are useful (but not always definitive) indicators of seepage impact (see the Technical Memorandum [GE, 2000]). N.A. Water Systems (2008e, Figure 1) presented box-and-whiskers plots of bicarbonate and pH for the background wells. Seepage-impacted water with a pH < 5.0 has not yet migrated far enough to reach equilibrium, or to react sufficiently, with carbonate minerals in the Zone 3 strata (Canonie, 1987, Table 4-5 indicates a measured CaCO3 content of 0.02 percent in the Zone 3 bedrock). A pH > 5.0 indicates either no seepage impact, or acid neutralization to varying degrees (usually a function of residence time and migration distance).
- In non-seepage-impacted areas, background water has approximately reached equilibrium with the carbonate minerals resulting in bicarbonate concentrations ranging from approximately 100 to 500 mg/L.
- Time-series of these two indicator parameters are very helpful (sometimes essential). See N.A. Water Systems (2008e, Appendix A) for time-series of pH and bicarbonate for the background wells.
- Time trends in the concentrations of major ions; in particular, decreasing ratios of Ca/Mg are associated with degrading groundwater quality (see Appendix B; e.g., Well EPA 14).
- Zone 3 time trends in the concentrations of many metals and radionuclides will usually increase as the water quality degrades from background to seepage-impacted (see Appendix B; e.g., Well EPA 15).

Seepage-impact extent is primarily based on evaluation of pH and bicarbonate concentrations over time in (1) seepage-impacted wells (e.g., Wells 613 and 517), (2) background and former background wells (e.g., Wells EPA 1 and 411), and (3) northern monitoring and extraction wells (i.e., the northern tracking wells, NW-series wells, and Well MW 7). Table 11 presents the historical monthly field parameter measurements for the northern tracking wells (from south to north: Wells 504 B, RW A, PB 2, PB 4, PB 3, NBL 2, and NBL 1). Table 12 presents the monthly field parameter measurements for the newer NW-series and MW-series wells. Quarterly laboratory analytical results for these wells are provided in Appendix B. Bicarbonate time-series for most Zone 3 monitoring wells are shown in Figure 39, while Figure 40 shows a subset of the wells (selected based on the seepage impact perimeter). Historical groundwater quality data (see Appendix B) from fully seepage-impacted wells indicate that it takes from one to three years, from the onset of geochemical changes associated with the arrival of seepage-impacted groundwater, for full seepage-impact to develop (unless the constituent transport is effected by pumping). Figure 35 shows the acidic core area of seepage-impacted water in 2018, which is similar to that depicted in 2017, with very slightly larger areas encompassed by the pH 4.0 and 5.0 contours. Groundwater quality along the northern tracking wells has been shown to have oscillated between degrading and improving trends (e.g., see NBL 1 and PB-series wells in Table 11); fully seepage-impacted water has exhibited very low pH values (e.g., Well NBL 1) and bicarbonate concentrations of 0 mg/L (additional details have been provided in previous Annual Reports [e.g., Chester Engineers, 2016]). This relatively large pH and bicarbonate variation over short distances indicates that the groundwater quality is highly heterogeneous on the local scale of the related well array and that the seepage-impact front is proximal to the wells. This feature is interpreted to reflect the capacity of pumped wells to locally draw background quality groundwater into areas of seepage impact. The variability is inferred to be an effect of the revised pumping program that began in 2005.

The monthly field parameter measurements made in the two currently monitored northern tracking wells (Wells RW A and NBL 2) are shown on Table 11. Well RW A is an extraction well that is becoming increasingly seepage impacted. The RW A laboratory bicarbonate concentration dropped below 100 mg/l in April 2016 and the field bicarbonate concentration dropped below 100 mg/L in September 2016; both have continued to decrease in 2018. The Well RW A field pH shows an overall decreasing trend from 2013 to 2014 but had been relatively stable around pH 6 during 2015 and 2016. During 2017, the decreasing trend was re-established, with monthly field pH measurements dropping below and pH 6. During 2018, the field pH values fluctuated but were stable within a range of about 0.4 pH units. Well NBL 2 continues to monitor background water quality; bicarbonate has decreased (with fluctuations) from a high of 414 mg/L in 2011 to about 300 mg/L but remained stable in 2018.

Monthly field parameter measurements made in the NW-series of wells and Well MW 7 (Table 12) provide the northernmost information on water quality. NW 1 and NW 4 are the easternmost of the NW-series wells and NW 3 and NW 5 are the westernmost. Seepage-impacted water is typically more prevalent towards the eastern limit of saturation; to the west the prevalence of background water increases as does the formation's saturated thickness. The following summarizes the interpretation of monthly field parameter data for the NW-series wells and Well MW 7:

- Well NW 1 (not pumped since May 2012) was the most seepage-impacted until it began improving after September 2011 and is now considered to represent mostly background water. However, field and laboratory bicarbonate concentrations decreased since 2017. During the period between November 2017 and October 2018, the bicarbonate decreased to a low of 256 mg/l in August 2018, then increased to 329 mg/l in October. The range of laboratory bicarbonate concentrations was 323 to 370 mg/l. Field pH fluctuated between 6.71 and 7.5 pH units.

- Well NW 4 (a seepage-impacted, very low flow-rate extraction well from which pumping was suspended in October 2015) showed somewhat less seepage impact than NW 1 until impact increased, beginning in September 2011. The NW 4 field bicarbonate concentration increased in November 2013 (200 mg/L) and has since decreased (18 mg/L in October 2018). Field pH measurements fluctuated during the November 2017 to October 2018 monitoring period (ranging from 5.81 to 6.66 units) but were generally slightly lower than the 2017 monitoring period.

- Well NW 2 (an extraction well) had shown little seepage impact through 2013. However, seepage impacts increased in 2014 through 2018 (reflecting a slight shift in seepage impacted water to the west or north as a result of the pumping). The 2018 NW 2 results indicate the continuation of a very slow decreasing trend in bicarbonate (the field bicarbonate concentration reached a minimum of 85 mg/L in August 2018 [Table 12]; the range of the four quarterly laboratory bicarbonate results was 75 to 116 mg/L [Appendix Table B.1]), and a pH range (5.83 to 6.14 units) slightly lower than the prior year.

- Wells NW 3 (not pumped since 2009) and NW 5 (pumping initiated during March 2016) have been historically interpreted as predominantly background water. They also have had greater saturated thicknesses than other NW-series wells. During the current monitoring period, NW 3 field measurements showed some variability in field pH (6.91 to 7.47) and bicarbonate concentrations (390 to 493 mg/l). These results for NW 3 are consistent with the interpretation of predominantly background water. NW 5 field measurements had indicated decreasing bicarbonate concentrations and decreasing pH, trends that accelerated after pumping was initiated in March 2014 and continued into the 2018 monitoring period. NW 5 field bicarbonate measurements have followed an overall decreasing trend (from a high of 627 mg/L in March 2011 to 9 mg/L in August 2018, followed by a slight increase in September (40 mg/L) and October 2018 (55 mg/L). The NW 5 field pH measurements have followed a similar trend: pH decreased from 6.95 in November 2015 to 4.80 in August 2018 (with a low of 4.52 units in April 2018) but increased in September (5.52 units) and October 2018 (5.86). The overall decreasing trends are interpreted to be the result of an increasing fraction of seepage-impacted water captured by pumping, whereas the recent increases may represent a shift in the capture area.

- Well MW 7 is considered partially impacted. The MW 7 bicarbonate concentration has followed an overall decreasing trend (from 416 mg/L in December 2013 to 201 mg/L in October 2018 [with a low of 189 mg/L in September 2018]) and a slightly lower average bicarbonate concentration for the November 2017 to October 2018 monitoring period (~212 mg/L) than the previous monitoring period (~220 mg/L). The MW 7 field pH fluctuated widely between 6.29 and 7.81 in 2018, similar to that reported during the previous monitoring period.

Figure 35 shows the northern edge of the seepage-impact front during October 2018 to be the same that depicted in the 2017 and 2016 annual reports where it encompasses Well NW 5 and adjoins Wells NW 2 and MW 6. NW 1 remains outside the seepage-impacted area. This is consistent with previous determinations of the seepage front extent over the past several years (e.g., Chester Engineers, 2016), which have focused on “full seepage impact” - defined as bicarbonate concentrations at or below 50 mg/L. NBL 1 was historically identified as the “end point well” of full seepage impact, which was appropriate given the very low field pH and bicarbonate concentrations of 0 mg/L. However, reductions in saturated thickness in the northern Zone 3 area have caused fewer wells to be available for sampling, which increased the reliance on historical samples (see Tables 11 and 12) that may not reflect current conditions. Additionally, field measurements have not been made at NBL 1 since February 2013, due to a sharp decrease in the well water level and an accumulation of sediment at the bottom of the well. The current position of the downgradient seepage extent accounts for the impacted water quality at pumping Well NW 5 and the partial seepage impacts observed at pumping Well NW 2 (more impacted than in 2017, with three monthly field bicarbonate concentrations and two of the four laboratory bicarbonate samples [range 75 to 115 mg/L] below 100 mg/L). The seepage front line also adjoins Well MW 6 (last sampled for field parameters in September 2015) as it has in previous years.

In summary, the 2018 water quality data in northern Zone 3 varied slightly with respect to 2017. Although the seepage-impacted water historically observed at NBL 1 just to the south has not “broken through” to the north, water quality changes in northern Zone 3, which in 2016 justified a slight shift in the mapped position of the downgradient extent of seepage impacts, have remained similar in 2018, although extraction Well NW 2 appears likely to become fully seepage-impacted in the future. It is anticipated based on current concentrations that seepage-impacted water will continue to be retarded by pumping from Wells NW 2 and NW 5 (to the degree pumping can be maintained).

EPA (2003) previously presented two sets of Stiff diagrams to evaluate geochemical data with respect to Zone 3 seepage impacts: (1) one set that showed EPA 14 in annual “snapshots” of water quality from October 1998 through October 2002 (these were also presented in GE, 2012b) and (2) a second set that presented Stiff diagrams for ten Zone 3 wells based on the October 2002 sampling (also presented in GE, 2012b). This information is considered with more recent geochemical data with respect to seepage impact classification and progression below. Additional details regarding these analyses are presented in previous annual reports (e.g., Chester Engineers, 2016, 2017).

- Well EPA 14 is fully impacted by tailings seepage, as exhibited by bicarbonate and metals concentration trends (see Appendix B and Table 14) but has shown some periodic variability interpreted to represent background water incursion. Stiff diagrams for Well EPA 14 in the annual water quality "snapshots" for October 1998 through October 2002 (EPA, 2003) show that before October 2000, the calcium-to-magnesium (Ca/Mg) ratio was greater than one and the earlier bicarbonate concentrations were consistent with background water quality but later became elevated (see Figure 39). From October 2000 to October 2002, the Ca/Mg ratio was less than one and bicarbonate became depleted. Modest exceedances of the aluminum and cobalt ROD standards in Well EPA 14 began in 2000, when the bicarbonate concentration decreased suddenly and sharply. Figure 40 shows that the bicarbonate at this location fell sharply to nondetect (zero) in July 2001, then increased to 188 mg/L in October 2004, and then fell to nondetect again in October 2006; this is interpreted as due to occasional mixing with background water (which is presently located nearby to the west; see Figure 35 in this report). Between October 2006 and October 2014, bicarbonate concentrations at EPA 14 remained at or very near nondetect levels. During 2015, bicarbonate concentrations and pH values increased (pH maximum 6.70 units, bicarbonate maximum 91 mg/L) during the January to July period (indicating some proportion of mixing with background water) but decreased again in October 2015 to values indicative of greater seepage impact (pH 4.47, bicarbonate <5 mg/L). Bicarbonate values remained below the detection limit in all samples until October 2017 (5 mg/L, this result that was equal to the detection limit and originally considered unreliable because it was qualified (holding time exceedance and detection in the laboratory method blank), which was the beginning of a slightly increasing trend that reached 55 mg/L in October 2018. The October 2018 field pH (5.55) increased slightly from October 2017 value (5.34) and the Ca/Mg ratio increased to approximately one during 2018.

- The first chemical measurements in Well NBL 1 were made in August 2001 (Appendix B), when the calcium-sulfate type of water was representative of background water quality. Subsequently, early stage seepage impact was shown by the gradual reduction of the Ca/Mg ratio from 2001 through October 2005 (Appendix B) and the beginning of decreasing bicarbonate concentrations around April 2004 (Appendix B, based on laboratory determinations of bicarbonate) and June 2004 (Table 11, based on field determinations of bicarbonate). Starting in January 2010, NBL 1 showed decreases in Ca/Mg ratio (0.80 in last analysis in January 2013) and significant increases in metals concentrations; full seepage impacts were subsequently indicated by the 2012 and January 2013 bicarbonate nondetects and pH values frequently less than 4 (although approximately 100 ft to the northeast at MW 6 [last sampled for full laboratory analysis in July 2014], the water quality in the most recent samples was notably better). It is also notable that the groundwater chemistry degradation in NBL 1 coincided with, and may be associated with, declining saturated thickness (i.e., consistent with the hypothesis developed by NRC, 1996). These closely spaced, large variations in groundwater quality are attributed to the effects of extraction well pumping in their vicinity, which causes variations in the proportion of seepage-impacted versus non-seepage-impacted water that reaches the wells. Monitoring of the northernmost part of Zone 3 in Section 36 indicates that this area is a complex zone of mixing of background and seepage-impacted water, rather than a singular advancing plume edge with a "sharp line" boundary.

- Invariably, some wells (or certain time spans at some wells) are difficult to classify because their groundwater chemistry tends to be gradational. For example, the geochemistry associated with Well 420 has long been considered “borderline” between background and seepage-impacted water quality which is consistent with its location between the area of formerly perennial alluvial recharge and that of tailings seepage. It is notable that the Well 420 water level was below the bottom of the screened interval for samples collected after January 2017 (there is a 5-ft section of blank well casing below the well screen); therefore, the reliability of these samples is suspect. The Stiff diagram and recent samples from this well, located along the western edge of the seepage-impacted area in Figure 35, indicate a calcium-sulfate type of background water. Bicarbonate concentrations in Well 420 samples suggest mixing of seepage-impacted water with background water but have remained in the background range. Over the one-year period from April 2006 to April 2007, bicarbonate dropped from 781 mg/L to 237 mg/L but subsequently increased and has been since following a fluctuating, slowly decreasing trend (Figure 40). The bicarbonate concentration in April 2015 fell below 400 mg/L for the first time since April 2007 and has remained there through the sample collected in October 2018 (314 mg/L). Historical data for other analytes (notably sulfate, uranium, and molybdenum) have been interpreted as indicating that the groundwater quality in the vicinity of Well 420 is “borderline” between background and seepage-impacted, that the seepage-impacted region is nearby, and that the groundwater quality may be degrading very gradually or has stabilized (Chester Engineers, 2017).
- Well 717, near the western edge of the seepage-impacted area in Figure 35, provides a third example of a calcium-sulfate type of water that was interpreted as predominantly background (largely non-seepage-impacted) in 2002 but subsequently became increasingly impacted. Starting during 2006, concentrations of several metals, and gross alpha activity have increased. Constituents that exceeded NRC License standards and/or revised EPA cleanup levels during 2018 included aluminum, beryllium, cobalt, manganese, nickel, uranium, and gross alpha. Combined radium and thorium-230 have also recently exceeded their revised standards. A sharp decline of bicarbonate from July 2002 (740 mg/l) to January 2009 (nondetect) is similar to that observed in Well EPA 14 (see Figure 40) and is interpreted to represent exhaustion of the local buffering capacity. The comparative water quality of 717 and EPA 14 are discussed further in Section 3.3.4.
- The other seven wells depicted with Stiff diagrams (EPA, 2003, Figure 6-8) represent seepage-impacted magnesium-sulfate types of waters. For example, in October 2018 (see Appendix B) upgradient Well 613 (in the southwestern part of the seepage-impacted area shown in Figure 35) showed a high sulfate concentration (8,490 mg/L, a Ca/Mg ratio less than one, nondetected bicarbonate, a very low field pH (2.94 units), and exceedances of NRC License standards or revised EPA cleanup levels for many parameters.

The October 2018 annual samples from extraction Wells RW A and RW 11 indicate that these wells have become increasingly seepage-impacted (Table B-1). Well RW A shows a slowly decreasing bicarbonate concentration trend (minimum 29 mg/L in 2018) and RW 11 has decreased since 2008 but may have stabilized (132 mg/L in October 2018). Both wells have increasing TDS and sulfate concentrations, Ca/Mg ratios below one, and fluctuating pH indicating that indicate that neutralization capacity is available but is being depleted and/or there continues to be mixing with background water. Well RW A data from October 2014 showed increases in metals and radionuclides, including aluminum, beryllium, lead, combined radium, thorium-230, Pb-210; all these concentrations subsequently decreased and remained at lower concentrations during 2018.

However, the RW A cobalt concentration in the October 2016, 2017, and 2018 samples exceeded the revised EPA cleanup standard. Well RW 11 has shown recent increases in several metals and radionuclides (including magnesium, cobalt, manganese, nickel, combined radium, Pb-210 and gross alpha) most of which have stabilized as of 2018.

With respect to the currently operating Zone 3 pumping containment remedy, observed changes in saturated thickness, water quality, and seepage impact extent in northern Zone 3 and reductions in pumping capabilities over time indicate that the northern Zone 3 remedy may be reaching its practicable limits. EPA anticipated this in the ROD (EPA, 1988b) in stating that, in event that saturated thicknesses cease to support pumping, remedial activity would be discontinued or adjusted to appropriate levels. EPA (1988b) also stated that it may be technically impracticable to achieve all cleanup levels in a reasonable time period, such that waivers to meeting certain constituent-specific ARARs may be required. Additionally, EPA (2013, 2018) has acknowledged the technical difficulties of achieving site groundwater cleanup levels using engineering controls and that institutional controls (ICs) may need to play a larger role in protecting human health. UNC has initiated the permitting process to install monitoring wells north of Section 36 (Figure B-2 in Appendix B) that are intended to support the adoptions of waivers, alternate standards or other administrative controls to close the corrective action program. The wells are anticipated to be installed in 2019.

3.3.3 Rate of Seepage Migration

Table 13 summarizes the key factors, locations, and criteria underpinning the past calculations of northward seepage travel times for Zone 3. During the period from 2003 to 2008, the northern seepage front was inferred to have advanced from Well PB 2 to Well PB 4, receded as a consequence of pumping of RW 11, RW 12, RW 13, and PB 2 (see N.A. Water Systems, 2007a), and then advanced to PB 4 again. The repeated advance, covering the same ground locations, reflects the pumping-related hydraulic “tug of war” occurring in the vicinity of the northern tracking wells. With the advent of pumping from the northern, NW-series extraction wells in February 2009, the older northern tracking wells became subject to influences from both upgradient and downgradient extraction wells. The purpose of the upgradient wells (i.e., the RW-series wells RW A, RW 11, RW 16, and RW 17) is primarily to dewater and recover contaminant mass, while the purpose of the downgradient wells (i.e., the NW-series, of which only NW 2 and NW 5 are operating as of November 30, 2017) is to form a hydraulic barrier. In so doing, these wells have also drawn the seepage front into their capture zones. The original purpose of calculating seepage-impact migration velocities for Table 13 equivalents, as a basis of predicting the progression of the impact reaction front, has been rendered moot by the designed actions of these extraction wells. Therefore, Table 13 has been included for reference but has not been updated for this report.

As described in Section 3.3.2, Figure 35 shows the position of the northern edge of the seepage-impact front during October 2018, which is identical to the location depicted in 2017 and 2016. The northern limit of seepage impact encompasses the impacted water quality at pumping Well NW 5 and adjoins the partially seepage-impacted pumping Well NW 2, both which have shown increasing seepage impacts in 2018. The seepage front line also adjoins Well MW 6 (last sampled for field parameters in September 2015) as it has in previous years. Field bicarbonate and pH measurements at Wells MW 6 and MW 7 show that there likely has been some mixing with seepage-impacted water. However, the pH at both wells has been above 6 units. These data are interpreted to indicate that the highly impacted water just to the south has not “broken through” to the north and that northward flow of seepage-impacted water is being retarded by pumping from Wells NW 2 and NW 5. Bicarbonate concentrations in MW 6 were below 200 mg/L for most of the period from early 2013 to mid-2015 and appeared to have a slightly increasing trend when last sampled (224 mg/L in September 2015), but earlier full analytical data (July 2012 to April 2014) indicates Ca/Mg ratios below one. The MW 7 field bicarbonate concentration has also followed an overall decreasing trend since December 2013 (from 416 mg/L to 201 mg/L in October 2018); the Ca/Mg ratio has declined over time but remains slightly above one (1.06) as of October 2018. It is anticipated based on current concentrations that seepage-impacted groundwater will continue to be retarded by pumping from Wells NW 2 and NW 5 (to the degree that pumping can be maintained).

3.3.4 Natural Attenuation System Performance Evaluation

The Zone 3 natural attenuation system comprises the hydro-geochemical interactions between the bedrock matrix, the anthropogenic background waters (derived from former groundwater discharge associated with historical mining operations that ceased in 1986), and the tailings fluids. The natural system is attenuating the seepage impacts by the processes of neutralization, precipitation, adsorption, and mixing with the background waters.

Natural geochemical processes slow the migration of constituents associated with the acidic seepage in Zone 3 (as in the Southwest Alluvium and Zone 1). These processes neutralize the acidic seepage, which causes the precipitation and adsorption of metals and radionuclides. Evidence of this neutralization process includes: (1) an overall increase in pH and corresponding decrease in concentrations of metals and radionuclides with increasing distance from the source area; and (2) gradual increase in bicarbonate for a few years followed by dramatic decreases. Shutoff of the remaining Stage II wells in 2000 enhanced the effectiveness of the natural attenuation processes in many parts of the seepage-impacted area.

The impact of natural attenuation of seepage impacts by geochemical processes for individual constituents in Zone 3 is discussed below (also see Table 14).

Sulfate and TDS

Sulfate and TDS are non-hazardous constituents and not regulated by NRC. Figure 41 is a graph of sulfate concentrations from 1989 through October 2018. Concentrations are relatively high closest to the tailings impoundment and Well 613 is the only monitoring location where sulfate concentrations (8,490 mg/L in October 2018) and TDS concentrations (11,100 mg/L in October 2018) exceed the revised EPA cleanup standards. As in the Southwest Alluvium, sulfate concentrations are controlled by geochemical equilibrium with gypsum (or anhydrite) and calcite. Although very high sulfate concentrations were present in the tailings fluids, such sulfate concentrations attenuate rapidly downgradient due to precipitation of gypsum. Earth Tech (2002c, Figure 3-13) demonstrated that sulfate concentrations decreased by about 85 percent between the North Cell and the seepage-impacted water at Well 613 via precipitation of gypsum (the saturation index of virtually all water samples with respect to gypsum hovers around unity). Moreover, there is a complete overlap between the range of sulfate concentrations in seepage-impacted and background water (except for Well 613). Slightly increased concentrations in recent samples from certain monitoring locations (e.g., Wells EPA 13, 717, 711, MW-7 and 517) suggest slightly increasing concentration trends, but most of these concentrations are within or near the historical concentration range. Overall, the marked stability of sulfate in almost all wells, throughout the duration of remedial pumping and in the absence of such pumping, demonstrates that sulfate concentrations are determined exclusively by the geochemical equilibria between natural minerals and waters rather than remedial operations.

Figure 41 shows that sulfate concentrations at Well EPA 14 have fluctuated significantly since 2000 and over a range of 1,670 mg/L to 4,520 mg/L since April 2013. Well EPA 14 is known to have become seepage-impacted in 2000; this being the main basis upon which NRC and EPA agreed to suspend pumping in the downgradient Stage 2 extraction wells (because the wells pulled seepage-impacted water further westwards). The observed periodic variability in the sulfate concentrations is interpreted to reflect chemistry changes related to background water incursion into the seepage impacted area.

Metals

UNC has presented information demonstrating that certain metals exceeding historical standards (e.g., arsenic and molybdenum) were primarily found in background water (e.g., Chester Engineers, 2015a). The revised background standards have lessened one of technical impediments (GE, 2009) to eventual Site closure which stated that "long-term monitoring data and basic geochemical considerations reveal some cleanup objectives to be unattainable." For most parameters, the establishment of BTVs through statistical analysis will incorporate and account for the geochemical influence on groundwater quality and facilitate the identification and assessment of contaminants of concern.

Figures 42A and 42B are time-series graphs of concentrations of selected metals in Zone 3 monitoring wells (the metals uranium and vanadium are discussed later with the radionuclides). There were no exceedances of the revised standards for cadmium, or molybdenum during 2018, but charts for these analytes are included because they were included in previous years. POC Well 613 is located near the center of the seepage-impacted area, closest to the source area, where field pH has ranged from 2.76 to 3.24 since this well was first monitored in 2000. This well shows the highest metals concentrations during October 2018 monitoring event for aluminum, beryllium, cadmium, cobalt, manganese, and nickel. Figure 43 is a map showing the extent of aluminum concentrations exceeding 5 mg/L (the EPA cleanup standard) based in the October 2018 monitoring event. This map distribution pattern has been approximately constant over time, regardless of an active remedy or not. The map illustrates that the distribution of aluminum exceedances was largely restricted to the southwestern part of the seepage-impacted area. The 5 mg/L contour position has been slightly adjusted from that shown on October 2017 map. The 2018 map shows notably higher aluminum concentrations in the samples from Wells 719 (2.93 mg/L in 2018, 0.3 mg/L in 2017) and EPA 14 (13.9 in 2018 and 8.7 mg/L in 2017). In previous maps, an isolated outlying area of elevated aluminum concentrations was also depicted to the north encompassing Wells PB 4 and PB 3 (both of which were last sampled for the full laboratory chemical list in October 2013), and NBL 1 (last sampled in January 2013). This area was removed for the 2018 map due to the lack of recent data. A second outlying area previously depicted to be encompassing extraction Well RW A (7.8 mg/L) on the October 2014 map (Chester Engineers, 2015a) was removed in 2015 because the concentration decreased (0.1 mg/L); the October 2018 RW A result (0.59 mg/L) continues to affirm the removal.

All of the wells sampled in the October 2018 monitoring event within the highly seepage-impacted area (i.e., acidic core area, Wells 517, 613, 708, 711, and 717) showed exceedances of the NRC License standards and/or revised EPA cleanup standards for aluminum, manganese, cobalt, beryllium, and nickel (except Well 708 for nickel and Well 711 for manganese). The NRC License standard for beryllium (0.050 mg/l) is higher than the EPA cleanup standard (0.004 mg/l); beryllium exceedances at some monitoring locations exceeded only the EPA standards, others exceeded both standards (Table 14). Well EPA 14 (which was in the core area in 2015 but has had a higher pH in subsequent years [5.55 in October 2018]) had exceedances of the EPA cleanup standards for aluminum and beryllium in October 2018. There were no 2018 exceedances in samples from other seepage impacted or partially-impacted wells (Wells 420, 719, EPA 13, RW 11, and RW A) except for a cobalt exceedance at Well RW A in October 2018.

Outside the seepage impacted area, there were no exceedances in samples from Wells NBL 2 or MW 7. However, unusually high arsenic concentrations exceeding the NRC license standard were detected in background Well NW 3 during 2018 (range 0.98 to 6.2 mg/L, see Table 14 and Appendix B Table B.1). These concentrations are considered to be related to background groundwater chemistry (e.g., see Chester Engineers 2015a); similar notable exceedances (maximum 2.5 mg/L) were historically reported in nearby Well NBL 1 from 2002 to 2008, under both background and partially seepage-impacted conditions The NBL 1 arsenic concentrations were typically lower under "full seepage-impact" conditions. The reported NW 3 arsenic concentrations may be associated with declining saturated thickness and the increasing exposure of coal (and possibly pyrite) in the in the lower part of Zone 3 to oxygen.

The depletion of neutralization capacity has stabilized the concentrations of metals at higher levels in some wells. For example, concentrations of beryllium, cadmium, cobalt, nickel, manganese, and aluminum stabilized at elevated levels in Well 717 between October 2008 and July 2009. This commenced as bicarbonate concentrations approached nondetect levels in October 2008 (and remained nondetect after January 2009). The same process occurred earlier in Well EPA 14, which is 330 ft upgradient of Well 717. The concentrations of most metals increased in Well EPA 14 after May 2000, when bicarbonate concentrations declined precipitously (Figure 39). The concentrations of these metals stabilized after July 2006, when the neutralization capacity was exhausted (as evidenced by the typical absence of detectable bicarbonate. However, from January to July 2015 and again from October 2017 to October 2018 metals concentrations decreased in response to increased bicarbonate concentrations (and pH values), indicating some proportion of mixing with background water.

Uranium, Vanadium, and Radionuclides

Figure 44A presents graphs of the uranium and vanadium concentrations and combined radium and thorium-230 activities from 1989 through 2018. Combined radium activities have been previously demonstrated to exceed the historical NRC/EPA standard (5 pCi/L) in Zone 3 background water (e.g., in NBL 1 samples; Chester Engineers, 2015a). In 2018, the only exceedances of the combined radium NRC/revised EPA standard (35.2 pCi/L) were in the April and July 2018 samples from NW-3 (37.8 and 56 pCi/L, respectively).

Historically, uranium, vanadium, and thorium-230 have been present above the standards in Well 613, which has an acidic pH (field pH 2.94 in October 2018) and is closest well to the source in Section 2. Downgradient within the acidic core of the plume toward the northeast, natural attenuation (neutralization, adsorption, or possibly precipitation) reduces the concentrations of these three constituents (e.g., in Well 708 [field pH of 3.08 in October 2018]). Accordingly, much lower concentrations are reported where the pH is more neutral. In the October 2017 monitoring event, exceedances of NRC and/or revised EPA cleanup standards were reported for thorium-230, uranium, and vanadium in Well 613 and for uranium in Well 717 (Table 14). Additional exceedances were reported for uranium in the January through July 2017 samples from Well 613 and the July sample from Well 717. Additional exceedances for thorium-230 were reported in the July 2017 sample from Well 517 and the January, April, and July samples from Well 717 and 613 (Appendix B). Vanadium attenuates rapidly, such that it was not detected at any other locations in Zone 3.

Figures 44B and 44C provide uranium isoconcentration maps from October 2018 (Figure 44B, two alternative contour interpretations are shown) and October 2002. The source of uranium in both background and seepage-impacted water in Zone 3 was not tailings seepage, but mine water, permitted to contain uranium concentrations up to 2 mg/L, discharged to Pipeline Arroyo for 17 years. Uranium has been historically detected at relatively elevated concentrations in both background and highly seepage-impacted wells. Over the longer term, uranium at Well 613 within Section 2 shows an overall decreasing trend that has been below 1 mg/L since January 2014. Just outside Section 2, uranium concentrations have followed an overall increasing trend in Well 517 but appear to have stabilized just below the NRC/EPA standard [0.395 mg/L]). Farther downgradient outside Section 2, uranium in seepage-impacted water typically attenuates such that the range of uranium concentrations in Zone 3 background water is higher than the range in seepage-impacted water (N.A. Water Systems, 2008e, 2008f). Among the historical evidence that uranium concentrations in background can exceed those in moderately seepage-impacted water was that NBL 1 had a higher uranium concentration in October 2002 (Figure 44C, 0.251 mg/L) under background conditions (seepage impact reached this well in January 2004) than most subsequent samples under moderately seepage-impacted conditions.

Uranium concentrations at Well 717 along the northwestern edge of the seepage-impacted area have shown an increasing trend since 2013 (to a July 2018 maximum concentration [0.755 mg/L] shown on Figure 44A, with a slightly higher concentration reported in the October 2018 duplicate sample [0.775 mg/L) during a period where seepage impacts have been sustained or increased, as evidenced by pH values less than 4 and increasing metals concentrations (see Appendix B, Table B.1). The observed uranium concentration variability is attributed to geochemical reactions occurring in the areas where seepage impacted water and background water interact such as where groundwater is transitioning from one type to the other.

The water chemistry along the contact between seepage-impacted and background water from Well EPA 14 to Well 420 (including Well 717) varies significantly over a very short distance (see Figures 35 and 43) and is subject to local redirection of groundwater flow by extraction Well RW 16 (and to a lesser degree Wells RW 17 and RW 11). Similar uranium concentration increases to that seen in Well 717 have previously occurred at other locations where seepage-impacted water is proximal to background water and/or where active pumping was drawing both background and seepage impacted water (e.g., Well EPA 14 [July 2004 to January 2005, maximum 1.05 mg/L], Well NBL-1 [January 2013, maximum 0.458 mg/L], and PB 4 [October 2013, 0.535 mg/L]). In some cases, the complex geochemistry at the reaction front has yielded unusual results (e.g., precipitation of amorphous aluminosilicates at EPA 14).

In previous annual reports (e.g., the 2014 Annual Report [Chester Engineers, 2015a]), the uranium isoconcentration contour pattern along the northwest part of the plume (approximately from Well 717 to NBL 1; including Well 420) was interpreted to show the effect of background water being drawn in, from west to east, to seepage-impacted water, under the action of former and current pumping. The two 2018 alternative maps in Figure 44B are provided (as they were in 2017) due to the uncertainty associated with the substantial water chemistry variability along the contact between seepage-impacted and background water, as well as the limited uranium data in the center of the seepage-impacted area. The Well 717 uranium concentration is likely to be a local effect of the seepage-impacted/background interaction as represented by the contours shown in Alternative 1. Alternative 2 provides for an alternative interpretation relating the Well 717 uranium to the acidic core of the seepage-impacted water, based on the low pH values observed at the well.

Interpretations of uranium concentrations (and groundwater chemistry in general) are likely to remain dynamic in this area as saturated thicknesses decline and groundwater flow directions vary due to extraction well pumping along the contact between different water types.

The historical Zone 3 gross alpha data indicate that this parameter tends to fluctuate and can exhibit significant exceedances of the NRC License standard/revised EPA standard (39.7 pCi/L) in seepage-impacted wells. During 2018, the standard was only exceeded in samples from seepage-impacted Well 717 (three samples in two quarters) (Appendix B).

Total Trihalomethanes (TTHMs)

Prior to the fourth quarter 2006, the TTHMs concentration shown in Appendix B equaled the chloroform concentration (i.e., chloroform is the only TTHM compound analyzed). Starting with the October 2006 sampling event, the TTHMs concentration represents the sum of the four component compounds (of which chloroform is one). Almost all Site groundwater samples show that the TTHMs concentration equals the chloroform concentration (i.e., chloroform is the only TTHM compound present). There were no TTHM concentrations detected above the NRC License standard and/or revised EPA standard (NRC/EPA standard, 80 µg/L) in samples collected during 2018 (Table 14 and Appendix B).

Historical TTHM concentrations in Well 613 have exceeded the NRC/EPA standard in most samples since October 2002, consistent with this well's proximity to the tailings source (see Figure 35). Well 613 concentrations have shown long-term fluctuations but increased by a factor of four from July to October 2002. Since then the concentrations have shown relatively large fluctuations that are superimposed on an overall decreasing trend since 2012. TTHMs were detected during 2018 at concentrations below the NRC/EPA standard in samples from Wells 517, 613 and 717. Low concentrations of TTHMs have been detected in almost all Well 517 samples since 1991. TTHMs had been regularly detected at Well EPA 14 from October 2006 to April 2013 but have not been detected in subsequent samples. Chloroform was first detected in Well 717 in July 2008, and beginning in October 2010, was detected at very low concentrations for 27 consecutive quarters through April 2017 (except for the primary samples (of sample-duplicate pairs) collected in October 2015 and January 2016, see Appendix B). TTHMs were detected in all 2017 Well 717 samples except the July primary sample and duplicate sample and the October primary sample and were detected in all 2018 samples (below 1 µg/L). These results support the inference that fully seepage-impacted water has migrated downgradient to 717. Wells 106 D and 518 also consistently showed chloroform detections until they ceased being sampled in 1991 and 2000, respectively (Appendix B). Other Zone 3 wells have shown, with very few exceptions, historical nondetects for chloroform and, since the fourth quarter of 2006, for TTHMs. This indicates that chloroform is attenuated by degradation, dispersion, and dilution, to levels that are generally nondetect but are otherwise always far below the NRC/EPA standard (which is equivalent to the primary drinking water standard).

Pb-210

Table 14 shows that Pb-210 was detected in samples from four wells (Wells 420, 717, NW 3 and RW 11) during the October 2018 monitoring event. All of the 2018 results were below the NRC License standard and EPA cleanup standard (5.7 pCi/L). The 2018 detections are not inherently indicative of impact from the tailings seepage; the maximum activity reported during 2018 was 4.9 pCi/L (January Well 717 duplicate sample) and all detected activities fall within the lower half of the range of 1 to 11 pCi/L defined by the minimum and maximum values associated with background water (N.A. Water Systems, 2008e, Table 5).

3.4 EFFICIENCY OF SEEPAGE-IMPACTED GROUNDWATER REMOVAL BY PUMPING

The Zone 3 pumping efficiency is declining with time. As Zone 3 pumping continues, more background water flows eastward to replace (and possibly mix with) the seepage-impacted water volume removed by pumping, resulting in a lower pumping efficiency. This process of inducing progressively more background water will lead to increased concentrations of uranium, and other parameters (e.g., molybdenum has been detected at significantly higher concentrations in background compared to seepage-impacted water).

All Zone 3 pumping well capacities decline over time. One important cause is loss of saturated thickness. UNC asserts that overall conditions are such that active remedial operations in Zone 3 are reaching the limits of their effectiveness. This is demonstrated by significant annual reductions in pumping volumes (the 2018 pumped volume was 16 percent less than 2017, and average pumping rates for each of the six recovery wells were below 0.3 gpm). As a result, continued operation will be met with diminishing returns, and/or will adversely affect groundwater quality in some ways as was seen more than a decade ago with the former pumping system. It will not be possible to pump out all of the seepage-impacted water. Seepage removal efficiency will be considered in the SWSFS as the means to evaluate the effectiveness of any proposed remedy alternatives utilizing pumping wells. Extraction wells having yields below the 1 gpm decommissioning criterion may be recommended to NRC for decommissioning in a revision to the pending License amendment request or in a future License amendment request. The evaluation will consider the differing objectives of the two sets of extraction wells (i.e., the upgradient RW-series wells and the downgradient NW-series wells).

SECTION 4
ZONE 1

4.1 CORRECTIVE ACTION SUMMARY

Zone 1 corrective action consisted of source remediation (neutralization and later dewatering of Borrow Pit No. 2) and pumping of a series of extraction wells from 1984 through 1999 (Earth Tech, 2002c). Well productivity in this hydrostratigraphic unit had always been very low. Earth Tech (2002c, Figure 4-1) summarized the pumping program for Zone 1, including the well systems pumped, the number of wells operating for each system, and the combined annual pumping rates. A maximum combined pumping rate of 14 gpm was achieved by the 17 East and North Cross-Dike Pump-Back wells. The productivity declined steadily over time, and by July 1999, when the system was decommissioned, the three remaining wells were yielding a combined annual average of 0.65 gpm. The three remaining Zone 1 recovery wells (615, 616 and 617) were decommissioned at the end of July 1999 in accordance with a letter from NRC dated July 30, 1999 (Earth Tech, 2002a), with the concurrence of EPA.

UNC has submitted a pending License amendment request (GE, 2015) and subsequent amendment to the License amendment request (GE, 2016b) to reconcile the license with recent corrective action programs advances and to recommend modifications to the performance monitoring program. For Zone 1, the License amendment request recommends the removal of Well EPA 2 and POC Wells EPA 4, EPA 5, and EPA 7, all of which are located outside Section 2 in Section 1. The License amendment request was supported by data from the previous sixteen years of post-shutdown monitoring, which indicated a gradual improvement in water from the Zone 1 POC wells (GE, 2015). There are few instances where the standards have not been achieved and there were only four exceedances of any NRC License standards outside Section 2 (i.e., at monitoring locations outside the property boundary in Section 1) during 2018. Nickel was detected at concentrations exceeding its NRC License standard in samples collected from Well EPA 7 in samples from all four quarters at concentrations ranging from 0.085 to 0.09 mg/L.

4.2 MASS OF CHEMICAL CONSTITUENTS REMOVED

The mass of chemical constituents removed was calculated for the 10-year period from July 1989 through July 1999. These calculations were presented in the previous annual reviews, and the final summary was presented in the 1999 Annual Review (Earth Tech, 1999).

4.3 PERFORMANCE MONITORING EVALUATION

4.3.1 Water Level Evaluation

The current water level monitoring component of the performance monitoring program comprises quarterly monitoring of water levels in 15 wells (Table 15) and has been in effect since the second quarter of 2000. Historical water level data for sampled Zone 1 wells through October 2018 are presented in Appendix C. Water levels for the fourth quarter of 2018 are shown on the potentiometric surface map in Figure 46. Water levels through time are shown on Figure 47.

Saturated thicknesses calculated from the October 2018 measurements in Zone 1 are presented in Table 16. This table shows that the Zone 1 hydrostratigraphic unit remains completely saturated in most of the down-dip wells: 505 A, 502 A, and 412 (in Section 36) and 142 and 143 (along the northern boundary of Section 36) (see Figure 46). During 2018, most of the wells continued to show overall decreasing potentiometric elevations (Figure 47); changes of potentiometric elevations in up-dip and down-dip wells indicate the broad pattern of the shift in the potentiometric field caused by groundwater drainage to the northeast in Zone 1. Long-term decreasing water levels up-dip to the south-southwest, at locations under less than fully saturated conditions, are a response to the continued flow of groundwater down-dip into partially saturated parts of the system. Figure 47 also indicates that the potentiometric levels in Wells 142, 143, and 412 (in the northern part of Section 36, where Zone 1 is fully saturated) reached a maximum and have recently begun to slowly decline. Wells 501 A, 502 A are gradually decreasing and the water level in Well 504 A has been approximately stable, with minor fluctuations since 2006.

Earlier groundwater flow in Zone 1 was approximately eastward, reflecting groundwater mounding and recharge from the borrow pits and the alluvium to the west. Since the dewatering of Borrow Pit No. 2 and termination of mine-dewatering groundwater discharge into Pipeline Arroyo, the former mounding has dissipated. Consequently, water levels in up-dip areas of Zone 1 (e.g., Wells 604, 614, and 515 A) have dropped significantly, though the rate of decline has reduced with the dissipation of recharge-induced mounding (see Figure 47). The rate of groundwater drainage is also limited by the unit's relatively low transmissivity, and the very low transmissivity of the underlying aquiclude.

UNC has submitted to NRC an ACL application for Zone 1 that presented a historical quantitative analysis of groundwater flow rates and directions (N.A. Water Systems, 2008g). In January 1983 the flow-direction azimuth (63°) had a strong easterly component. During later time periods the flow azimuth gradually rotated to the north, resulting in an azimuth of 24° during October 2007. This indicates that as the formerly higher groundwater mound has gradually continued to dissipate over the years, the northerly dip of the Zone 1 sandstone has exerted greater control on the flow direction. Darcy seepage velocities have gradually fallen through time. During January 1983, the groundwater velocity was 93 ft/yr, and by October 2007 the velocity had fallen to 40 ft/yr (a reduction of 57 percent).

4.3.2 Water Quality Evaluation and Current Extent of Seepage-Impacted Water

The current water quality monitoring component of the Zone 1 performance monitoring program is summarized in Table 15 and comprises quarterly sampling in eight wells. Table C.1 in Appendix C provides historical constituent concentration data through October 2018 and Table 17 summarizes the constituents detected in Zone 1 during October 2018. Both of these tables also include the Zone 1 NRC License standards and revised EPA cleanup levels to facilitate direct comparison with the groundwater data.

The temporary saturation created by the infiltration of former mine-dewatering groundwater discharges is considered the background water for Zone 1 (EPA, 1988b; 1998). This anthropogenic groundwater was later seepage-impacted by acidic seepage from Borrow Pit No. 2 in the Central Cell (compare Figure 2 and Figure 48). These seepage fluids contained elevated concentrations of metals, radionuclides, and major ions, including sulfate and chloride. Source remediation (neutralization and subsequent dewatering of the borrow pit, and capping of the Central Cell), continued neutralization of the seepage by natural geochemical processes, and mixing with the background water have reduced concentrations of most constituents below the NRC License standards and revised EPA cleanup standards (as well as historical standards). However, as discussed below, exceedances of some constituents may still occur in Zone 1.

It is important to realize that the historically reported exceedances of NRC License standards and EPA cleanup standards in some wells represent background water quality. For example, since 1989, background Well EPA 4 (in Section 1) had (1) persistently shown exceedances of the historical EPA sulfate standard; (2) generally shown exceedances of the manganese ROD standard; and (3) shown concentrations of combined radium that have fluctuated above and below the ROD standard (5 pCi/L, which NRC revised in 2006 to 9.4 pCi/L [NRC, 2006] and subsequently revised to 12.1 pCi/L [both NRC and EPA]). Almost all of these results are below the current NRC license standards and revised EPA standards that take background geochemistry into account. Background water quality is discussed further in Section 4.3.3 (Natural Attenuation System Performance Evaluation).

Water quality has improved since shutoff of the pumping wells, indicating that the degree of seepage impact is diminishing. Zone 1 seepage impacts have been delineated (Figure 48) by chloride concentrations greater than 50 mg/L (Earth Tech, 2000a). The extent of seepage impacts has diminished gradually over time (e.g., compare 2008 Annual Report Figures 48 and 49, which show that the area of seepage impact contracted from 2007 to 2008). The seepage impact boundary in the 2012 Annual Report (Chester Engineers, 2013) was extended to the north by approximately 250 ft in order to include Well 619 (Figure 48) after the October 2012 “spot” sampling of Wells 617 and 619. The 2012 boundary position has been maintained in the current report. Well EPA 5 has shown a long-term, gradual reduction in chloride concentrations from a maximum of 289 mg/L in April 1992 to 38 mg/L in October 2018 and has stabilized with minor fluctuations (only one result since April 2008 exceeded 50 mg/L – refer to Appendix C). Well EPA 7 chloride concentrations gradually increased for several years but stabilized and decreased in 2018. Measurements exceeded the EPA cleanup standard (250 mg/L) in 2013 (one monitoring event), 2015 (three events), 2016 (one event), and 2017 (two events), but were all below the standard in 2018. Chloride is a non-hazardous constituent and a secondary contaminant. The EPA cleanup standard for chloride derives from the New Mexico Water Quality Act; 250 mg/L is also the federal SMCL (this constituent does not have a federal primary MCL).

The zone of seepage impact has migrated predominantly toward the northeast and the north-northeast. Farther eastward, components of migration are limited by the proximity of the eastern edge of saturation. The acidic “core” of the seepage-impacted zone is approximated by the area where pH is inferred to be less than 4.0 (orange area in Figure 48). Figure 49 shows historical field pH values for Zone 1 wells through October 2018. Well 604 has persistently shown the lowest pH; as discussed below, it also is the most highly seepage-impacted well. This well shows a long-term increasing trend in pH values, stabilizing since 2015 (Figure 49). Figure 49 shows that, starting in approximately 1990, acid neutralization and buffering resulted in substantial pH increases in Wells 515 A, 516 A, and EPA 7. However, during the last several years the water quality has been declining in 515 A in the following ways: (1) field pH decreased from 7.21 in January 2011 to 6.13 in October 2018 (although it appears to have stabilized); (2) sulfate increased from 5,060 mg/L in January 2011 to 6,510 mg/L in October 2018; and (3) bicarbonate sharply increased from 321 mg/L in July 2010 to 916 mg/L in April 2013, then has since decreased slightly to 823 mg/L in October 2018. The increase in bicarbonate accompanied by the decrease in pH indicates that relatively acidic seepage-impacted water has moved through this location and the water is being buffered by reaction with calcium carbonate.

UNC has demonstrated (e.g., Chester Engineers, 2012c, 2014b) that pre-mining (natural) groundwater in Zone 1 is encountered along the northern boundary of Section 36 in Wells 142 and 143; that this natural groundwater is overlain up-dip by post-mining/pre-tailings (background) water; and that the interface between these two types of groundwater is not migrating to the north. The natural and background waters would provide effective barriers to any potential Zone 1 COC transport to the north of Section 36.

The Zone 1 NRC POC wells include Wells 604 and 614 within Section 2 and Wells EPA 4, EPA 5, and EPA 7 in Section 1. Wells EPA 4 and EPA 5 lie outside the mapped seepage-impacted area. During 2018, only two constituents (nickel and TTHMs) were detected in POC well samples at concentrations that exceeded NRC License standards (Table C.1, Appendix C). Nickel concentrations exceeded the NRC License standard (0.070 mg/L) in all four quarters in Well 604 samples (within Section 2) and in all four quarters in EPA 7 samples (outside Section 2). The October 2018 TTHM concentration from POC Well 614 (within Section 2) exceeded the NRC License standard (80 µg/L). NRC License standards for TTHMs and nickel were also exceeded at non-POC Well 515A during 2018. The reported results were similar to recent historical data with the exception of the TTHM exceedance in Well 614 (172 µg/L), which was the highest concentration since 2012.

EPA cleanup standards, for constituents that are not regulated by NRC (or for which the EPA cleanup standard is different from the NRC License standard [e.g., nickel]) were exceeded at the following locations (the number of quarterly exceedances are shown in parentheses):

- Well 515 A – TDS (4), sulfate (4), chloride (4), and manganese (4).
- Well 604 –cobalt (4), nickel (1).
- Well 614 – chloride (4).
- Well EPA 7 –cobalt (4).

The 2018 cobalt concentrations for EPA 7 increased slightly over 2017, ranging from 0.07 mg/L in April and July to 0.08 mg/L in October, slightly above the EPA cleanup standard of 0.05 mg/L. The 2018 cobalt and nickel concentrations detected in Well 604 were similar to recent results and lower than historical results at this location.

Nitrate concentrations in samples from Well 614 (within Section 2) exceeded the EPA standard (190 mg/L) twice in 2016 and 2017 (Table C.1) but were all below the EPA standard in 2018. Nitrate concentrations have followed an overall increasing, fluctuating, trend since July 2005; however, the recent exceedance concentrations are within the range of historical results at Well 614 and the October 2018 result (160 mg/l) was significantly below the EPA standard. Chloride concentrations at Wells 515 A and 614 also exceeded the EPA standard (250 mg/L), as has frequently occurred at these locations historically.

Sulfate, TDS, and manganese are non-hazardous constituents that have historically been reported to exceed Site standards. The concentrations of sulfate and TDS reflect geochemical equilibrium of the groundwater with gypsum. There were no exceedances of the revised standards for any of these constituents at any well outside Section 2 during 2018. These data affirm the NRC staff's position (NRC, 1996) that sulfate, manganese, and TDS should not be used as a basis to implement corrective action. The sulfate and TDS concentrations in Well 515 A at the Section 2 boundary increased slightly from 2011 through 2016 but appear to have stabilized in recent years. Manganese concentrations in Well 515 A samples have followed an overall decreasing trend since mid-2008, increased slightly in 2017 and have resumed their decreasing trend in 2018. UNC has determined that Well 515 A does not meet performance criteria associated with low flow groundwater sampling methods, which limits the ability to collect representative samples.

Many other aspects of water quality have continued to improve since shutoff of the pumping wells, confirming that the degree of seepage impact is diminishing in both time and space. Natural attenuation processes include acid neutralization by:

- Reaction with the Zone 1 bedrock (which has a calcite [calcium carbonate] component of 0.03 percent [Canonie, 1987; Table 4.5]);
- Mixing with the neutral background water;
- Precipitation of metals and radionuclides; and
- Adsorption of metals (excluding manganese) and radionuclides.

These processes attenuate pH, metals, and other seepage constituents. The relatively low transmissivity of Zone 1 slows migration and increases residence time for the attenuation processes.

4.3.3 Natural Attenuation System Performance Evaluation

The Zone 1 natural attenuation system comprises the hydro-geochemical interactions between the bedrock matrix, the anthropogenic background waters (derived from former mine-dewatering groundwater discharges), and the tailings fluids. The natural system is successfully attenuating the seepage impacts by the processes of neutralization, precipitation, adsorption, and a degree of passive mixing with the background waters. Previous annual reports have indicated some constituents will remain at above-standard concentrations because of the inherent geochemical characteristics of the Zone 1 background water; however, the revised Site standards better account for background geochemistry.

Table 18 shows the predicted geochemical performance of the Zone 1 natural attenuation system (revised from Earth Tech, 2002c). In summary, sulfate and TDS concentrations outside Section 2 are expected to meet the revised EPA cleanup standards that take into account the gypsum equilibrium in background groundwater. Similarly, manganese is expected to meet the revised EPA cleanup standard outside Section 2; Well 515 A is the only location that currently exceeds the standard. The remaining metals and radionuclides are expected to meet the standards through attenuation by neutralization and adsorption, although Well EPA 7 currently exhibits nickel and cobalt concentrations that slightly exceed NRC and EPA standards, respectively. Chloride may meet the EPA cleanup standard outside Section 2 in the future. Well EPA 7 in Section 1 had exhibited a gradually increasing concentration trend, exceeding the standard twice during 2017, but did not exceed the standard in 2018. Outside of Section 2, TTHMs have always met the NRC/EPA standard and, based on trends, this condition is expected to continue. The individual constituents of concern are discussed below.

Sulfate and TDS

Sulfate and TDS are non-hazardous constituents and are not regulated by the NRC. Sulfate concentrations exceed the revised EPA cleanup standard in seepage-impacted water at one well (515 A) in Zone 1. Figure 50 shows historical sulfate concentrations through October 2018; Figure 51 shows the extent of sulfate exceedances during October 2018. The time-series indicate that the operation of extraction wells prior to July 1999 did not have a discernable influence on sulfate and TDS; sulfate concentrations in Zone 1 are controlled by the system's equilibrium with gypsum and they are broadly stable, with few exceptions. Based on this stability, sulfate and TDS concentrations in wells outside Section 2 are expected to meet the revised EPA cleanup standards, which take into account the gypsum equilibrium in background groundwater. There is some uncertainty because sulfate and TDS concentrations in Well 515 A at the Section 2 boundary increased slightly from 2011 through 2016 but appear to have stabilized.

Manganese

Manganese is a non-hazardous constituent in water that is not regulated by NRC. Manganese concentrations exceed the revised EPA cleanup standard in seepage-impacted water (Well 515 A) in Zone 1 within the Section 2 boundary. Concentrations have generally decreased over time as the acidic seepage has been neutralized, but the magnitude of the decrease is largely controlled by the bicarbonate concentrations (Earth Tech, 2000a). Historical manganese concentrations through October 2018 are shown on Figure 52 and tabulated in Appendix C. The extent of manganese concentrations that exceeded the revised EPA cleanup standard during October 2018 is shown on Figure 53. Figure 52 shows that the long-term decreasing trend for manganese in Well EPA 7, from January 1998 through October 2008. Since then, concentrations varied between 1.22 and 3.02 mg/L, but remained well below the revised EPA standard. Well 604 manganese concentrations decreased from January 2004 through April 2015. Since then, concentrations varied between 3.39 and 4.19 mg/L. The concentration in October 2018 was at the low end of this range. Well 515 A concentrations had shown a sharp decline from 13.1 mg/L in July 2012 (Figure 52) and appear to have stabilized, with some fluctuations, since October 2012. In October 2018 the concentration in 515 A was 6.90 mg/L. The overall decline is very likely related to the substantial increase in bicarbonate concentrations at this location since July 2010.

Bicarbonate concentrations in seepage-impacted wells are related to the waters' degree of neutralization of acidic seepage. Figure 54 shows historical bicarbonate concentrations through October 2018. As discussed above regarding Zone 3, marked declines of bicarbonate concentration are indicative of (sometimes temporary) exceedance of the local buffering capacity of the natural geochemical system (i.e., the flux of acidity temporarily exceeds the rate of buffering). The plunge of bicarbonate concentration in Well EPA 5 from January 2000 to May 2000 is such an example (the EPA 5 bicarbonate concentration continued to decrease through 2014 but appears to have stabilized within the range of 45 to 80 mg/L). A second example of historical bicarbonate trends is provided by Well EPA 7 (Figure 54), where formerly very low bicarbonate concentrations have increased step-wise beginning in July 1990, with additional upward steps in January 1994, again in October 1998, and again in May 2000. Since April 2010, concentrations have varied between 580 and 689 mg/L. The concentration in October 2018 was at the low end of this range. The rising concentrations indicated that the natural attenuation neutralization capacity has not been depleted. While tailings-impacted water may be reaching this location the buffering capacity has not been overcome by the flux of acidity. Bicarbonate concentrations at Well 614 have shown sharp fluctuations in the past and did so again in 2018, having risen from 755 mg/L in July to 1550 mg/L in October. The October 2018 concentration was within the range of concentrations typical of the period prior to 2011.

The seepage-impacted wells that have had bicarbonate concentrations greater than 1,000 mg/L (Wells 614, 516 A, and EPA 5) either have never had manganese exceedances or have had a significant decrease in manganese concentration to below the revised cleanup standard (5.4 mg/L). In contrast, seepage-impacted wells with lower bicarbonate concentrations, such as Wells 515 A, 604, and EPA 7, have historically had elevated manganese concentrations. However, even among these wells the effect of bicarbonate on manganese concentrations is well illustrated by data from Well EPA 7. Since July 2001, bicarbonate concentrations in Well EPA 7 (in Section 1) have exceeded 500 mg/L (Figure 54) and the manganese concentration steadily declined through October 2008 (Figure 52). Since then the manganese concentrations have been below the revised cleanup standard and the bicarbonate fluctuated within an overall stable trend. This geochemical behavior has previously been analyzed by Earth Tech (2000c). Another example of this correlation is Well 515 A, where the recent increase of bicarbonate concentrations (Figure 54) correlates with decreasing manganese concentrations (Figure 52, Appendix C).

In contrast to seepage-impacted wells, higher manganese concentrations at Well EPA 4 represent background water quality. Similarly, Well EPA 8, located beyond the tailings-impacted zone in background water to the east of EPA 4, also showed higher manganese concentrations through the termination of groundwater quality monitoring in January 2000. Most of the other constituents at EPA 8 had been fluctuating to steady since 1989 (Appendix C).

In summary, the limited neutralization capacity in background water results in elevated manganese concentrations that exceeded the revised EPA standard. The revised EPA standard is based on a statistical analysis of background manganese concentrations and appropriately accounts for these geochemical conditions. The only location where manganese concentrations currently exceed the revised EPA cleanup standard is Well 515 A, where concentrations have declined significantly over time but appear to have stabilized (with fluctuations); exceedance of the revised EPA manganese standard within the property boundary will continue at those locations where there is insufficient neutralization capacity to reduce the manganese concentrations. UNC agrees with NRC (1996) that manganese is not a useful indicator of seepage impacts or remediation success and it should be removed as a parameter of concern for all the reasons that have been discussed.

Chloride

Chloride concentrations in Well EPA 7 in Section 1 were below the EPA standard (250 mg/L) for all four quarters in 2018 after exhibiting a gradual increase and multiple standard exceedances over the past few years (see Appendix C). Chloride is a non-hazardous constituent and a secondary contaminant that is not regulated by NRC. Chloride concentrations at Wells 515 A and 614 also exceeded the EPA standard, as has frequently occurred at these locations since the start of monitoring during 1989. The EPA cleanup level for chloride derives from the New Mexico Water Quality Act; 250 mg/L is also the federal SMCL (this constituent does not have a federal primary MCL or an NRC License standard). Based on observed historical chloride concentration fluctuations in Zone 1 monitoring wells, it is possible that chloride will continue to meet the EPA cleanup level outside Section 2 in the future.

Cobalt and Nickel

As has been the case since 2014, nickel was the only metallic hazardous constituent that exceeded its current NRC License standard outside the UNC property boundary in Zone 1 during 2018. Nickel concentrations exceeded the NRC License standard (0.07 mg/L) at Well EPA 7 in all four 2018 samples (range 0.085 to 0.09 mg/L). There were no exceedances of the revised EPA cleanup level outside Section 2. Figure 55 shows historical nickel exceedances at both EPA 5 and EPA 7. Historical nickel concentrations had decreased at both wells such that there were no detections from April 2005 to January 2014 at EPA 7, and from July 2007 to October 2011 at EPA 5. Subsequent to those periods, nickel concentrations at both wells have periodically exceeded the current License standard (see Appendix C). Within Section 2 during 2018, nickel concentrations exceeded standards at Well 515A (NRC License standard) and at Well 604 (both NRC License standard and EPA cleanup level). The ranges of reported concentrations for these wells were similar to those in previous years.

Cobalt is not regulated by NRC. Cobalt concentrations exceeded the EPA standard (0.05 mg/L) at Well EPA 5 in July 2015 (0.06 mg/L) and the five previous quarters (range 0.07 to 0.1 mg/L), but all samples collected since then have been equal to or below the EPA standard. Cobalt concentrations exceeded the EPA standard (0.05 mg/L) in all four samples collected in 2018 from Well EPA 7 (range 0.07 to 0.08 mg/L) and Well 604 (range 0.085 to 0.112 mg/L).

Figure 55 shows that historical cobalt concentrations decreased at Wells EPA 5 and EPA 7 and were below the standard between October 2007 and January 2013. Following a pattern similar to nickel concentrations, cobalt concentrations in both wells increased briefly, subsequently decreased, and in EPA 7, increased again in the second half of 2017 and 2018. The extent of cobalt and nickel exceeding the EPA and NRC standards, respectively, during October 2018 is shown in Figure 56. The area is the same as that shown for October 2017, because the October 2018 cobalt and nickel concentrations are similar. Other metals are attenuated within the property boundary.

Cobalt and nickel typically do not adsorb sufficiently to reduce their concentrations below their standards until the pH is approximately 6.5 or more (Earth Tech, 2002c). For example, cobalt and nickel concentrations in Well EPA 7 historically have fluctuated around their respective standards as the pH has increased to above 6.0. Neutralization of tailings seepage in Well EPA 7 (pH rose steadily from approximately 4 to 7 throughout the 1990s) has been the geochemical impetus for reductions in concentrations to levels below the standards for cobalt in April 2002 and nickel in January 2003. Empirically (Appendix C) it appears that a pH of approximately 6.0 may promote adsorption sufficient for reduction of concentrations to below the standards for both parameters at most monitoring locations. However, fluctuating nickel and cobalt concentrations observed at Wells EPA 5 and EPA 7 from 2013 through 2018 do not appear to consistently correspond directly with the relatively small changes in pH during this period (Appendix C). It is possible that these fluctuations are related to local changes in redox conditions or the formation of inorganic dissolved complexes.

With the exception of the previously described variability at Wells EPA 5 and EPA 7, the cobalt and nickel time series (Figure 55) empirically demonstrate that natural attenuation occurs in two senses: over time at a given location, and spatially downgradient of the eastern part of the Central Cell. This evidence of continuing metals attenuation in upgradient areas suggests that conditions for attenuation will ultimately be re-established at downgradient locations in Section 1.

Combined Radium-226 and Radium-228 and Gross Alpha

Similar to the metals, combined radium is attenuated by neutralization, precipitation, and adsorption. Historical combined radium activities through October 2018 are presented in Figure 57. There were no exceedances of the NRC/EPA standard for combined radium (12.1 pCi/L) at any Zone 1 monitoring location during October 2018 (Table 17) or the other 2018 monitoring events (Appendix C).

Table 17 shows that there were no exceedances of the NRC License standard for gross alpha activity in the October 2018 samples. Exceedances of the gross alpha standard in Zone 1 wells have occurred historically but not recently.

Total Trihalomethanes (TTHMs)

During October 2018, TTHM concentrations exceeding the NRC/EPA standard (80 µg/L) were detected at Well 515 A and Well 614, both of which are within the property boundary. The range of TTHM concentrations at Well 515 A in 2017 (74 to 240 µg/L) was within the range of concentrations detected since January 2012. The October 2018 sample from Well 614 had a TTHM concentration of 172 µg/l, which is the only exceedance at this location since July 2016 but is within the range of historical concentrations. Only very low TTHM concentrations were detected at wells located in Section 1 during 2018 (maximum 1.4 µg/l in Well EPA 7).

Pb-210

Table 17 shows that there was one Pb-210 detection in the October 2018 sample from Well 515A; this detection (1.4 pCi/L) was at a concentration below the NRC License standard (4.7 pCi/L). Pb-210 was also detected below the NRC License Standard in the April 2018 samples from Well 515A, Well EPA 4, EPA 5, and EPA 7 (refer to Appendix C, Table C.1).

4.4 ALTERNATE CONCENTRATION LIMITS APPLICATION

In December 2008, UNC submitted an ACL application (N.A. Water Systems, 2008g) to NRC for TTHMs in POC Well 614 and nickel in POC Well 604. Both wells are located along the eastern property boundary in Section 2 (see Figure 48). This document followed NRC's guidance for organizational content and included sections addressing hazard assessment, exposure assessment, and corrective action assessment (including an As Low As Reasonably Achievable (ALARA) demonstration).

During 2011, NRC stated that this ACL application is unacceptable because the proposed POEs (Wells EPA 5 and EPA 7) are not located on UNC property. This proposal was made because there is no space for more wells to the east of the Central Cell in Section 2, such that there would be spatially separate POC wells (604 and 614) and POE wells. Nonetheless, it is important to understand the key issues related to UNC's ACL application from 2008, which are summarized next.

The NRC License standard for nickel is 0.07 mg/L (revised from 0.05 mg/L in 2015). The New Mexico Water Quality Control Commission (NMWQCC) standard for nickel is 0.2 mg/L and is the basis of the revised EPA cleanup standard identified in 2015 (Chester Engineers, 2015b). The NRC License standard for TTHMs is 0.08 mg/L; this is the same value as the federal MCL (and current EPA standard). The NMWQCC standard for TTHMs is 0.1 mg/L.

In developing the proposed ACLs, UNC conducted concentration trend analyses from the final shutoff of Zone 1 pumping wells in July 1999 through July 2008. In addition, historical groundwater quality has been reviewed for all monitoring wells in Zone 1. Based on these observations, UNC proposed the ACL of 0.4 mg/L for nickel at POC Well 604, and the ACL of 0.3 mg/L for TTHMs at POC Well 614.

Since the termination of pumping, most constituent concentrations have progressively reduced through natural geochemical processes (as discussed in detail for all constituents in this 2018 Annual Review Report). Fluctuations of nickel and cobalt concentrations at Zone 1 Wells EPA 5 and EPA 7 during the past few years are within the range of historical concentrations and may be related to local geochemical fluctuations. The analysis presented in the ACL application indicated that the spatial extent of Zone 1 seepage impact is stable to diminishing, and that natural attenuation by neutralization (buffering) and adsorption is occurring for the metals (including nickel), and that attenuation by degradation, dilution, and dispersion is occurring for chloroform. Evidence of continuing metals attenuation in upgradient areas suggests that conditions for attenuation will ultimately be re-established at downgradient locations in Section 1.

The 28-year history of continuous groundwater quality monitoring in Zone 1 (and Site-wide) provides a sound empirical basis for evaluating contaminant transport and attenuation. The key conclusions of the ACL application are summarized (in italics) below:

- *There was no nickel or chloroform at concentrations above standards in any Section 1 well.* (This statement has since remained valid for chloroform. However, subsequent to this application, nickel concentrations detected at Wells EPA 5 and EPA 7 in Section 1 have exceeded the historical standard and the current NRC standard [but not the revised EPA standard]. These recent fluctuations of nickel concentrations at Wells EPA 5 and EPA 7 are within the range of historical concentrations. Nickel concentrations in Well EPA 5 dropped below the NRC Standard in July 2015 and have since remained below this level. Nickel concentrations in Well EPA 7 have recently exceeded the NRC Standard.)
- *The long monitoring history provides more than sufficient time to detect exceedances and to evaluate trends.*
- *Source area concentrations within Section 2 show decreasing long-term trends.*
- *Constituent concentrations progressively decrease downgradient.*
- *Hydraulic gradients and groundwater flow rates are diminishing over time.*
- *Groundwater quality is expected to continue its improvement at the proposed point-of-exposure (Wells EPA 5 and EPA 7) from levels which are very largely below Site standards.* (However, note the statement about EPA 5 in the top bullet of this list).
- *There are no Zone 1 exceedances of the License GWPS in Section 36 (UNC property) or Section 1 (Indian Trust Land property), nor are there exceedances of any hazardous constituents within seepage-impacted water outside of Section 2.* (However, note the statement about EPA 5 and EPA 7 in the top bullet of this list.)
- *A large part of Zone 1 in Section 1 is dry, and this hydrostratigraphic unit is physically and chemically non-viable for sourcing domestic or stock water supply wells. Treatment of either the seepage-impacted or background water, to potable quality, would be extremely expensive and is not feasible.*
- *The proposed Zone 1 remedy of No Further Action plus ACLs will be protective of human health and the environment.*
- *UNC has demonstrated ALARA conditions in Zone 1.*

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

This annual review evaluated the performance of the natural systems in all three Site hydrostratigraphic units and the active remediation in Zone 3. As was the case for the 2015 through 2017 Annual Reports, the Site groundwater standards used for data comparisons in this annual report are those that had been revised in conjunction with the establishment of statistically based BTVs during 2015. NRC issued a License amendment to update site GWPSs (NRC, 2015) and EPA approved the use of the revised cleanup levels (EPA, 2015) for remedy alternative evaluation in the ongoing SWSFS. These agency actions lessen one of the technical impediments (GE, 2009) to eventual Site closure which stated that “long-term monitoring data and basic geochemical considerations reveal some cleanup objectives to be unattainable.” For most parameters, the establishment of background threshold values through statistical analysis will incorporate and account for the geochemical influence on groundwater quality and facilitate the identification and assessment of contaminants of concern.

In the Southwest Alluvium and Zone 1, the natural systems have functioned as effectively as when active remediation took place. Acidic seepage is being neutralized, resulting in attenuation of metals and radionuclides. During 2018, extraction well pumping continued in part of Zone 3. This extraction of seepage-impacted groundwater started with the hydrofracture program in 2005 and was supplemented, starting in 2009, with extraction from certain NW-series wells located near the northernmost area of seepage impact. The purpose of the upgradient wells (e.g., the hydrofracture or RW-series wells) is primarily to dewater and recover contaminant mass, while the purpose of the downgradient wells (e.g., the NW-series Wells NW 2 and NW 5) is to form a hydraulic barrier. The Zone 3 pumping system has been declining in performance and has approached the limit of its effectiveness due to declining saturated thicknesses, as predicted.

5.1 CONCLUSIONS

Below are some of the key conclusions of this report:

- The following four monitoring wells do not meet performance criteria associated with low flow groundwater sampling methods, which limits the ability to collect representative samples at these locations: Wells GW 3 and 632 (both are POCs in the Southwest Alluvium), Well 515 A (non-POC in Zone 1) and Well 517 (POC in Zone 3). Well 719 also has a very low volume available for sampling and is considered to have “borderline” suitability for low-flow sampling methods. Additionally, Wells GW 2 and GW 3 can no longer be sampled safely, because of their proximity to the unstable edges of the Pipeline Arroyo canyon. UNC has submitted a License amendment request (GE, 2015) and a subsequent amendment (GE, 2016b) that remove POC Wells GW 2 and GW 3 from the monitoring program. Wells 632, 517, 515 A, and 719 should also be removed from the monitoring program.
- Data collected from Wells 420 and 446 are no longer valid. As of April 2017, the water level in Well 420 was below the base of Zone 3 and the screened interval of the well. Therefore, water level measurements and water samples collected since April 2017 at this location are considered not to be representative of Zone 3 (the water chemistry associated with Zone 2 [primarily shale and coal] would be expected to be dissimilar). Well 420 may be influenced by active pumping of the RW-series wells, so it could also become relevant again if pumping were to be terminated. Well 446 water level measurements are also no longer valid because the water level is below the bottom of the screened interval (there is a 10-ft section of blank well

casing below the well screen) and it is difficult to measure due to the presence of a floating natural oil lens.

- Uranium concentrations in the Southwest Alluvium are not related to the migration of uranium in tailings fluids. The range of uranium concentrations in the background water has been empirically shown to be the same as the range within seepage-impacted water (GE, 2006). Uranium and bicarbonate concentrations are usually covariant in the Southwest Alluvium groundwater, i.e., when the concentration of the bicarbonate parameter changes, uranium changes with it, provided that there is uranium available for dissolution or desorption in the sediments. This observation has held for most Southwest Alluvium wells for both the period of active pumping period (more than 11 years) and post-pumping monitoring period (more than17 years) and is expected based on principles of aqueous chemistry.
- Concentrations of uranium in the Southwest Alluvium are an indicator that natural attenuation is at least as effective a remedy as pumping. With the exception of POC Well GW 3, which was last sampled in 2015, uranium concentrations and concentration time trends have either stabilized or shown decreasing trends since the pumps were turned off. The increasing trend of concentrations at GW 3 did not necessarily relate to the shutoff. Since July 2009, the increasing uranium concentration trend is the result of covariance with bicarbonate concentrations. Additionally, the very low saturated thickness in GW 3 (2.07 ft in July 2015 and projected to now be dry) may contribute to elevated dissolved constituent concentrations (i.e., consistent with the hypothesis developed by NRC [1996]) that dissolved salt concentrations will increase as the aquifer system dries out). As the saturated thickness declined, the well may have become isolated or hydraulically disconnected from the Southwest Alluvial flow system; groundwater under these conditions is not representative of typical groundwater quality because it has greater opportunity to geochemically evolve and reach local equilibrium with the formation. Uranium concentrations at non-POC Well EPA 25 and upgradient Well 509 D, which had previously shown increasing trends, have stabilized. Well EPA 25 uranium concentrations (October 2018, 0.126 mg/L) remain substantially lower than the NRC License standard; the previous slightly increasing trend was the result of covariance of uranium and bicarbonate concentrations. Well 509 D is located outside the zone of influence of the former pumping wells; therefore, it is not a good indicator of whether there is a benefit to pumping.
- The source of uranium in the Southwest Alluvium was not the tailings seepage but mine waters with uranium concentrations up to 2 mg/L that were historically discharged under permit into the Pipeline Arroyo and infiltrated into the Southwest Alluvium. Empirical data show that the elevated uranium concentrations in the mine discharge (i.e., the historical background concentrations) have been broadly and significantly attenuated in the alluvium in that most of the seepage-impacted wells have shown overall stable trends since the pumping system shutdown. The interaction of the uranium in the Southwest Alluvium sediments with varying geochemical (e.g., bicarbonate) or hydrologic factors (e.g., reductions in saturated thickness or isolation from the groundwater flow system) may result in variable concentration trends accompanied by localized exceedances of the Site uranium standard (e.g., at Wells GW 3 and 509 D). The UPL95-based BTV calculation method is inappropriate for uranium in the Southwest Alluvium; the uranium standard in the Southwest Alluvium should be waived because the principal source of uranium for both background and seepage-impacted waters was not tailings seepage, but rather the mine discharge water. The observed spatial and temporal variability in Southwest Alluvium water uranium concentrations is related to factors that are unaccounted for in the UPL95-based BTV analysis. Those factors include the likely heterogeneity of the uranium distribution in the sediments; uranium concentrations in the Southwest Alluvium attenuate via adsorption and/or precipitation such that background uranium concentrations decrease with increasing distances downstream and away from the

arroyo centerline. It also is not possible to ensure that a standard will be achieved consistently throughout the seepage-impacted area as the geochemistry fluctuates and water levels decline over time. Moreover, the standard will only be attained upon extraction of all water in the alluvium, which is not practicable.

- Groundwater levels in the Southwest Alluvium continued to decline (with periodic fluctuations observed) in 2018, indicating that the artificially recharged zone of saturation continues to become naturally dewatered as the groundwater drains down the arroyo. The water level in SBL 1 has a lower rate of decline than other local wells. The water level elevation in SBL 1 has been higher than the water level elevation in Well 624 since 2015 and the SBL 1 water level elevation has been higher than that in Well EPA 25 since July 2018.
- The position of the downgradient limit ("nose") of the 1,000 mg/L bicarbonate isoconcentration contour shown in Figure 8 has been modified from that presented in the 2014 through 2017 Annual Reports. Because the piezometric elevations in SBL-1 and points east are depicted as being higher than in Well 624 (in Figure 3A), Well SBL-1 is no longer downgradient of the "nose" of the plume. Instead rather hydraulic gradients are to the west south-west and the "nose" of the 1,000 mg/L bicarbonate isoconcentration line is to the north of SBL 1, as depicted on Figure 8. The saturated thickness map in figure 3B is also consistent with this interpretation, because the greater saturated thickness to the north of SBL-1 implies that the mass flux would be greater in the area north of SBL-1.
- During 2018, both onsite and offsite seepage-impacted water quality in the Southwest Alluvium met the NRC GWPSs (Appendix A) except for a slight exceedance of the NRC License standard for Pb-210 (5.9 pCi/L) in the sample from Well 801 in April 2018 (6.8 pCi/L). This result is unusual in that it was the only Pb-210 detection in the 2018 Southwest Alluvium samples, including the two subsequent samples from Well 801. There have only been 13 exceedances of the current standard in Southwest Alluvium samples since 1989 and the only previous exceedance at Well 801 was reported in January 1997. There is no basis to infer that this Pb-210 result reflects any impact of tailings seepage.
- Except for 12 uranium NRC License standard exceedances in samples collected from Well GW 3 between July 2012 to July 2015, the groundwater quality at all POC wells has met the current License standards since January 2011. Historically, exceedances of the current NRC License standards are otherwise infrequent and most occurred more than a decade ago.
- Hydraulic containment is not a necessary feature of the corrective action program in the Southwest Alluvium because of the geochemical attenuation that occurs naturally. The natural system is as, or more, effective than pumping for controlling the migration of the constituents of concern. There were no exceedances of the NRC License standards in offsite seepage-impacted water during 2018, and only a slight exceedance of the revised EPA standard for chloride in an April 2018 sample from Well GW 1, just outside the Section 2 boundary. The only other recent exceedances include the multiple recent uranium detections at Well GW 3 (2012 to 2015) and chloride in two GW 1 samples (one each in 2015 and 2017). The GW 3 (2012 to 2015) uranium exceedances appear to be an isolated and localized effect of desaturation and non-representative samples (because of insufficient flow to meet the low-flow sampling SOP).
- The non-hazardous constituent manganese exceeds its revised EPA standard in the Southwest Alluvium in seepage-impacted wells within Section 2 and in background Well SBL 1 within Section 10.
- During 2018, there were four exceedances of the NRC License standard for nickel in the Southwest Alluvium in background Well SBL 1 (in Section 10).

- Locally increasing trends of common dissolved ion concentrations are unrelated to tailings seepage; they derive from the reaction of the anthropogenic recharge water with natural alluvium materials. Heterogeneous distributions of the soluble alluvium minerals is the most significant factor affecting the intra-well and inter-well variations in the concentrations of common dissolved ions (e.g., sulfate and TDS).
- Evaluation and prediction of constituent concentrations in the Southwest Alluvium is predicated on understanding the geochemical evolution of both the background water quality and later changes associated with passage of the seepage-impact front. Hazardous constituents derived from seepage impact are effectively attenuated to acceptable concentrations within the Site boundary.
- Both the Southwest Alluvium and Zone 1 natural systems are at least as effective as the former active remediation systems in attenuating the seepage-impacted water. Acidic seepage is being neutralized, resulting in attenuation of metals and radionuclides. Natural geochemical conditions related to gypsum equilibrium and bicarbonate availability will control sulfate and manganese concentrations in both hydrostratigraphic units, regardless of whether or not the extraction wells are operated.
- Groundwater elevations in Zone 1 continued to decline overall (with small fluctuations) in 2018, causing the saturated thickness that accommodates groundwater flow and constituent migration to diminish in the up-dip parts of this bedrock stratigraphic unit.
- There were four exceedances of NRC License standards in Zone 1 outside Section 2 in 2018. The Well EPA 7 nickel concentrations slightly exceeded the NRC License standard in all four samples collected in 2018. Cobalt concentrations exceeded the revised EPA cleanup standard at Well EPA 7 in all four samples as well. These fluctuating concentrations are within the range of historical concentrations and may be related to local changes in redox conditions. Evidence of continuing metals attenuation in upgradient areas suggests that conditions for attenuation will ultimately be re-established at downgradient locations in Section 1.
- Outside the UNC property boundary in Zone 1, the post-pumping groundwater quality continues to improve overall (Tables 17 and 18). The concentrations of non-hazardous constituents sulfate and TDS in Wells EPA 5 and EPA 7 reflect geochemical equilibrium of the groundwater with gypsum; there were no exceedances of the EPA cleanup levels for these constituents outside Section 2 during 2018. Chloride concentrations in samples from Well EPA 7 in Section 1 were below the EPA standard (250 mg/L) for all four quarters in 2018 after having exhibited a gradual increase and multiple standard exceedances over the past few years (see Appendix C). Chloride is a non-hazardous constituent and a secondary contaminant that is not regulated by NRC.
- Groundwater levels in Zone 3 continued to decline in 2018, indicating that the anthropogenic zone of saturation continues to diminish as the groundwater drains down the dip of the bedrock layers. Pumping of extraction wells since 2005 has locally accelerated the rate of water level decline in northern Zone 3. The declining water levels prevented sample collection at four northern Zone 3 monitoring wells (NBL 1, PB 3, PB 4, and MW 6) during 2018.
- The Zone 3 NRC POC wells (517, 613, 708, and 711) are within the acidic "core" of the seepage-impacted water. The following constituents exceeded NRC License standards at the POC wells during the 2018 quarterly monitoring (the numbers in parentheses indicate the number of exceedances):
    - Well 517 –nickel (4).
    - Well 613 – beryllium (4), nickel (4), vanadium (4), uranium (4), and thorium-230 (4).
    - Well 708 – beryllium (4), and nickel (2).

- Well 711 –nickel (4).

- NRC License standards for beryllium, nickel, uranium, and gross alpha were also exceeded in seepage-impacted water at non-POC monitoring locations during 2018. Additionally, the NRC license standards for arsenic and combined radium were exceeded in samples from northern Zone 3 Well NW 3, which is interpreted to monitor predominantly background water. The arsenic concentrations were unusually high (range 0.98 to 6.2 mg/L); however similar notable arsenic exceedances (maximum 2.5 mg/L) were historically reported in nearby Well NBL 1 from 2002 to 2008, under both background and partially seepage-impacted conditions. The reported NW 3 arsenic concentrations may be associated with declining saturated thickness and the increasing exposure of coal (and possibly pyrite) in the in the lower part of Zone 3 to oxygen.
- EPA cleanup standards were exceeded for beryllium, TDS, sulfate, aluminum, cobalt, and manganese during 2018. These are constituents that are not regulated by NRC, or for which the EPA cleanup standard is lower than the NRC License standard (e.g., beryllium).
- The source of uranium in both background and seepage-impacted water in Zone 3 was not tailings seepage, but mine water, permitted to contain uranium concentrations up to 2 mg/L, discharged to Pipeline Arroyo for 17 years. Uranium has been historically detected at relatively elevated concentrations in both background and seepage impacted wells in Zone 3. The 2018 pattern of uranium concentration contours in the central and northern seepage-impacted area continues to illustrate incursion of background water due to pumping as described in 2017. Uranium concentrations at Well 717 along the northwestern edge of the seepage-impacted area have shown an increasing trend since 2013 (to an July 2018 maximum concentration of 0.755 mg/L) during a period where seepage impacts have been sustained or increased, as evidenced by pH values less than 4 and increasing metals concentrations. The observed uranium concentration variability is attributed to geochemical reactions occurring in the areas where seepage impacted water and background water interact such as where groundwater is transitioning from one type to the other along the contact between both water types from Well EPA 14 to Well 420 (including Well 717). Along this band (or contact) water quality varies significantly over a very short distance (see Figures 35 and 43) and is subject to local redirection of groundwater flow by extraction Well RW 16 (and to a lesser degree Wells RW 17 and RW 11). Reactions between these two water types and the host rock have been described and led to the decision to cease groundwater recovery operations in the Stage II recovery wells in 2000 (GE, 2000). Uranium concentrations are likely to remain dynamic in this area as saturated thicknesses decline, and groundwater flow directions vary due extraction well pumping.
- Pumping in the northernmost part of Zone 3 has created a mixing zone of background and seepage-impacted water; therefore, the mapped position of the seepage-impacted water is dynamic. Based on bicarbonate and pH data, the northern edge of the seepage-impact front for October 2018 is the same as that shown for October 2017 and 2016: encompassing Well NW 5 and adjoining Wells NW 2 and MW 6. NW 1 is shown to be outside the seepage-impacted area based on its water chemistry. It is anticipated that seepage-impacted groundwater water will be retarded by pumping from Wells NW 2 and NW 5 (to the degree pumping can be maintained). UNC continues to evaluate the chemistry and water levels in the northern Zone 3 wells, which may result in further modifications to the pumping rates to optimize the extraction system operations or to cease operations.
- All Zone 3 pumping well capacities decline over time. As anticipated by Appendix A of the ROD (EPA, 1988b), one important cause is the loss of saturated thickness. All of the Zone 3 extraction wells have yields below 0.3 gpm and saturated thickness has decreased significantly

in seepage impacted areas. NW 2 is reportedly reaching the end of its capability as a pumping well as pore spaces are clogged by fine clays and flow to the well has been reduced. It will not be possible to pump out all of the seepage-impacted water in Zone 3. Additionally, UNC has demonstrated that the efficiency of seepage-impacted water removal has declined with time and is expected to continue to degrade. Extraction wells having yields less than the 1 gpm decommissioning criterion may be recommended to NRC for decommissioning in a revision to the pending License amendment request or in a future License amendment request. The evaluation will consider the differing objectives of the two sets of extraction wells (i.e., the upgradient RW-series wells and the downgradient NW-series wells).

- UNC believes that overall conditions are such that active remedial operations in Zone 3 are reaching the limits of their effectiveness. As a result, continued operation will be met with diminishing returns, and/or will adversely affect groundwater quality in some ways as was seen a decade ago with the former pumping system. For example, the migration of background water toward the Zone 3 extraction wells will lead to increased concentrations of uranium and other parameters (e.g., molybdenum).
- UNC personnel report some concerns about the reliability of the extraction well flowmeter data as the saturated thickness declines, due to both the low flow rates/volumes and the presence of suspended clays that coat the flowmeter components and periodically render them inoperable. UNC will continue to evaluate flow monitoring methods in the future as needed.
- There are no exceedances of NRC License standards for hazardous constituents in Zone 3 outside the UNC property within seepage-impacted groundwater.

5.2 RECOMMENDATIONS

5.2.1 Recommendations for Closure of Southwest Alluvium Remedial Action

The predicted performance of the Southwest Alluvium natural attenuation system is summarized on Table 6. The continuing assessment of natural attenuation in this annual report is the basis for the following recommendations for the Southwest Alluvium corrective action system:

1. Monitoring wells that do not meet performance criteria associated with low flow groundwater sampling methods (which limits the ability to collect representative samples) or are otherwise unsuitable for monitoring should be decommissioned. In the Southwest Alluvium, these wells include, but may not be limited to, Well 632 (POC in the Southwest Alluvium), Well GW 3, and Well GW 2 (the latter two can no longer be sampled safely). UNC may submit a revision to the pending License amendment request or a new License amendment request to NRC that will specify recommended modifications to the performance monitoring program, including recommended replacement wells, where applicable and available.
2. Decommission the pumping wells and implement a No Further Action remedial alternative. Attenuation via natural geochemical processes has been shown to be at least as effective as pumping.
3. The corrective action monitoring program for the Southwest Alluvium under the NRC Source Materials License should be discontinued (except for selected POC wells). With the exception of the recent Well GW 3 uranium exceedances (which can be explained on the basis that the well is not providing representative samples), the groundwater quality at all POC wells has met the License standards since January 2011. UNC submitted a License amendment request to NRC in October 2015 requesting this change.

4. The uranium standard in the Southwest Alluvium should be waived, because the principal source of uranium for both the background and seepage-impacted water was the permitted mine discharge water rather than the tailings seepage. Recent exceedances at Wells GW 3 and 509 D demonstrate that it is not possible to ensure that a standard will be achieved consistently throughout the seepage-impacted area because of the interaction of uranium in the Southwest Alluvium sediments with varying geochemical (e.g., bicarbonate) or hydrologic factors (e.g., reductions in saturated thickness, or isolation from the groundwater flow system). The standard will only be attained upon extraction of all water in the alluvium, which is not practicable.
5. Sulfate, TDS, and manganese should be waived as constituents of concern or removed from the Southwest Alluvium monitoring program based on NRC's (1996) background water quality analysis report and multiple reports by UNC (many of which are summarized in the SWSFS Part I, N.A. Water Systems, 2007b; and Chester Engineers, 2009b). A Technical Impracticability waiver was previously recommended for sulfate and TDS but would not be necessary under the revised EPA cleanup standards. In the Southwest Alluvium, there are no sulfate or TDS concentrations in seepage-impacted water or manganese concentrations in seepage-impacted water outside Section 2 that exceed the revised EPA cleanup standards.

5.2.2 Recommendations for Zone 3 Remedial Action

The continuing assessment of remedial extraction pumping, seepage impact extent, and natural attenuation in this annual report is the basis for the following recommendations for the Zone 3 corrective action system:

1. Consider terminating extraction pumping, particularly from the upgradient hydrofracture well series (i.e., RW-series), which is likely drawing in background water from the west. Some constituents have higher concentrations in background water, compared to seepage-impacted water. The evaluation will consider the differing objectives of the two sets of extraction wells: (1) those of the upgradient hydrofracture (RW-series) wells are primarily to dewater and recover contaminant mass, and (2) that of the downgradient wells (NW-series) is to form a hydraulic barrier.

    - Zone 3 extraction wells having yields less than the 1 gpm decommissioning criterion may be recommended to NRC for decommissioning in a revision to the pending License amendment request or in a future License amendment request. UNC will submit License amendment requests as needed in 2019 to decommission recovery and monitoring wells that do not meet operating criteria.

    - Declining yields from the current extraction-well array indicate that hydraulic control is temporary. This has always been the case for pumping in Zone 3. Zone 3 saturated thicknesses are quite low (especially considering well losses), and any future pumping to reduce the pressure head will obtain only limited short-term results. Because the bedrock slope drives groundwater flow to the north, there is an irreducible elevation head that cannot be decreased by pumping. Counteracting this force is the reduction of effective porosity by the seepage-induced chemical alteration of feldspar to clay. This reduces the bedrock permeability, which retards the migration of the seepage. Eventually, a balance will develop between the irreducible elevation head and the trapping of the seepage-impacted groundwater due to the diminished bedrock permeability, retarding further migration of seepage-impacted water. Although the timing and location of such a balance cannot be predicted, such a development is likely. UNC recommends that consideration be given to other regulatory tools to manage the inherent physical limitations to the Zone 3 bedrock-groundwater system (e.g., ACLs, TI Waivers, MNA, and ICs).

2. Monitoring wells that do not meet performance criteria associated with low flow groundwater sampling methods (which limits the ability to collect representative samples) or are otherwise unsuitable should be decommissioned and/or removed from the monitoring program. In Zone 3, these wells include, but may not be limited to, Well 517 (POC in Zone 3), Well 504 B (dry), and Well 446 (water level is below the bottom of the screened interval). The collection of water samples and water levels from Well 420 should be suspended because samples are no longer representative of Zone 3, until such time that the water level elevation at this well is above the base of Zone 3. Well 420 may be influenced by active pumping of the RW-series wells, so it could also become relevant again if pumping were to be terminated. UNC may submit a revision to the pending License amendment request or a new License amendment request to NRC that will specify recommended modifications to the performance monitoring program, including recommended replacement wells, where applicable and available.

3. Sulfate and TDS should be removed from the Zone 3 monitoring program. Monitoring data indicate that sulfate and TDS concentrations do not exceed revised Site standards in seepage-impacted water outside Section 2.

4. The wells being planned for installation at locations north of the Section 36 boundary continue to be recommended to support the adoptions of waivers, alternate standards or other administrative controls to close the corrective action program. UNC has initiated a process to locate, permit, drill, construct, and operate these wells. Information obtained during 2018 suggested that Zone 3 may be deeper at the proposed monitoring locations than previously understood, which would reduce the number of wells needed to meet the monitoring objectives. Consequently, the monitoring well plan was adjusted to comprise the installation of three wells, followed by evaluation of geologic and water quality data to confirm that the monitoring objectives have been met. It is anticipated that the wells will be installed during 2019.

5. It is anticipated that seepage-impacted groundwater water will be retarded by pumping from Wells NW 2 and NW 5 (to the degree pumping can be maintained). UNC continues to evaluate the chemistry and water levels in the northern Zone 3 wells, which may result in further modifications to the pumping rates to optimize the extraction system operations or to cease operations.

5.2.3 Recommendations for Closure of Zone 1 Remedial Action

The Zone 1 seepage-impacted area has attained ALARA goals. The predicted performance of the Zone 1 natural attenuation system is summarized on Table 18. Implement the following recommendation toward closure of the Zone 1 corrective action system:

1. As first put forth by the NRC (1996), and further developed in several geochemistry (Earth Tech, 2000c) and annual reports (Earth Tech, 2000e; N.A. Water Systems, 2004, 2005, 2007a), there is no method to achieve the historical EPA standards for sulfate and TDS, which are exceeded in background groundwater. Sulfate, TDS, and manganese concentrations meet the revised EPA cleanup standards in wells outside Section 2 (but continue to exceed standards within Section 2 at Well 515 A). There were four minor exceedances of the NRC standard for nickel (but not the EPA standard) and four minor exceedances of the EPA cobalt standard during 2018. Zone 1 has already been dewatered to the extent that is feasible. Metals concentrations are demonstrated

to attenuate in two senses: over time at a given location, and spatially downgradient. It is not appropriate to tie remediation progress to (1) sulfate or TDS concentrations which reflect geochemical equilibrium of the groundwater with gypsum or (2) chloride concentrations that only slightly exceed a standard equivalent to, or based on, an SMCL. Chloride is a non-hazardous constituent and a secondary contaminant that should not be considered to be an ARAR. Remedial alternatives to be presented in Part III of the SWSFS should be closely coordinated with any necessary TI Waiver(s), ACL applications, and ICs.

2. Monitoring wells that do not meet performance criteria associated with low flow groundwater sampling methods (which limits the ability to collect representative samples) should be decommissioned. In Zone 1, these wells include, but may not be limited to, Well 515 A (non-POC in Zone 1). UNC may submit a revision to the pending License amendment request or a new License amendment request to NRC that will specify recommended modifications to the performance monitoring program, including recommended replacement wells, where applicable and available.

3 UNC has submitted a pending License amendment request (GE, 2015) and subsequent amendment to the License amendment request (GE, 2016b) that recommends, for Zone 1, the removal from the monitoring program of Well EPA 2 and POC Wells EPA 4, EPA 5, and EPA 7 all of which are located outside Section 2 in Section 1. The License amendment request was supported by data from the previous sixteen years of post-shutdown monitoring, which indicated a gradual improvement in water from the Zone 1 POC wells (GE, 2015).

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TABLES

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TABLE 1A
Chronology of Events
June 1977 to December 2018
UNC Church Rock Mill Tailings Site, Church Rock, New Mexico

Event	Date
The UNC milling operations began.	June 1977
Dam on south tailings disposal cell is breached, releasing an estimated 93 million gallons of uranium mill tailings and pond water to Pipeline Canyon and the Rio Puerco. EPA Region 6 and New Mexico Environmental Improvement Division (NMEID) respond to release.	July 1979
New Mexico Environment Improvement Division orders UNC to implement discharge plan to control contaminated tailing seepage.	October 1979
UNC announces mill closing due to depressed uranium market.	May 1982
Site placed on the National Priorities List (NPL) of Superfund Sites due to off-site migration of radionuclides and chemical constituents in ground-water.	1983
EPA conducts Remedial Investigation (RI) field activities to determine the nature and extent of ground-water contamination in the three water-bearing formations at the Site.	March 1984-August 1987
In 1984, UNC blocked EPA access to the Church Rock facility, and EPA brought an action to compel site access. UNC counterclaimed seeking declaratory and injunctive relief. The U.S. District Court granted an EPA motion to dismiss the UNC counterclaims, and UNC provided access to the Site to EPA. *United States v. United Nuclear Corporation,* 610 F Supp. 527, 528 (D.N.M., 1985).	April 18, 1985
NMEID returns Uranium Mill Tailings Radiation Control Act (UMTRCA) federal regulatory program to the U.S. Nuclear Regulatory Commission (NRC).	June 1986
EPA and NRC sign MOU coordinating EPA's CERCLA ground-water remedial action with NRC's reclamation and closure activities under the Source Materials License.	August 26, 1988
EPA releases RI and Feasibility Study (FS) report along with proposed plan of action field sheet.	August 1988
EPA issues ROD for extraction of contaminated water and evaporation of the extracted water as the remedy for ground-water contamination outside of the Tailings Disposal Site.	September 30, 1988
NRC approves a UNC submitted closure plan for the reclamation of the mill site.	September 1988
UNC submits Remedial Design Report.	April 1989
Remedial action implemented in Zone 1 – Borrow Pit No. 2 dewatered.	April 1989
EPA issues Unilateral Administrative Order (UAO) Docket No. CERCLA 6-11-89 to UNC requiring UNC to implement the Site CERCLA ground-water operable unit remedy determined by the ROD.	June 29, 1989
Remedial action implemented in Zone 3 – 12 new extraction wells begin pumping.	August 1989
Remedial action implemented in Southwest Alluvium – 3 new extraction wells begin pumping.	October 1989
Ground Water Corrective Action Annual Review 1989 documents remedial action construction completion.	December 1989
United States had brought action against UNC in 1991 for response cost recovery under CERCLA; and in late 1992, the U.S. District Court issued an opinion and order granting a U.S. motion for partial summary judgment on the issue of costs and denying a UNC cross motion for summary judgment. *United States v. United Nuclear Corporation*, 814 F Supp. 1552 (D.N.M., 1992).	December 28, 1992
NRC issues a background-water quality study that recommends higher concentrations of background constituents than presented in the ROD.	1996
First Five-Year Review completed.	September 24, 1998
NRC, EPA, and NMED approve the decommissioning of 10 Zone 3 wells, 3 Zone 1 wells, and 1 Southwest Alluvium well because they meet the decommissioning criteria of producing less than 1 gallon per minute (gpm).	July 30, 1999
NRC approves eliminating the Section 1 portion of Zone 3 as a point of exposure.	September 16, 1999

TABLE 1A Chronology of Events June 1977 to December 2018 UNC Church Rock Mill Tailings Site, Church Rock, New Mexico	
UNC submits request to terminate all Zone 3 pumping and for Technical Impracticability waiver to EPA, NRC and NMED.	May 2000
All but three Zone 3 wells decommissioned in accord with criterion.	June 2000
EPA approves UNC's request to shut down remaining three Zone 3 wells to slow seepage migration rate.	November 2000
License Amendment No. 31 allows UNC to temporarily suspend the corrective action pumping in Zone 3.	December 29, 2000
License Amendment No. 32 approves the conversion of the Zone 3 Phase II extraction wells to monitoring wells.	March 8, 2001
UNC submits Draft Tribal Resolution and Environmental Right-of-Way to the Navajo Nation to form basis for ICs.	March 2001
EPA gives UNC approval to temporarily shut down Southwest Alluvium extraction wells and an 18-month Natural Attenuation Test is conducted.	February 2001 through July 2002
UNC submits Final Report and Technical Impracticability Evaluation – Southwest Alluvium Natural Attenuation Test to EPA, NRC and NMED.	November 2002
UNC submits proposal to conduct hydraulic fracturing pilot test.	May 21, 2003
UNC conducts the hydraulic fracturing pilot test in Zone 3.	June 2003
Second Five-Year Review completed.	September 18, 2003
Meeting between EPA, Bureau of Indian Affairs (BIA), and the Department of the Interior (DOI) to discuss access issues in connection with the Site ground-water monitoring program on Navajo Allotment lands.	December 5, 2003
UNC submits Final Report – Hydraulic Fracturing Pilot Test Results and Preliminary Full-Scale Design, United Nuclear Church Rock Facility.	December 2003
EPA comments on the Final Report – Hydraulic Fracturing Pilot Test Results and Preliminary Full-Scale Design and directs UNC to perform supplemental feasibility study (SFS) for Zone 3.	March 10, 2004 and March 19, 2004
EPA approves Final Report - Hydraulic Fracturing Pilot Test Results and Preliminary Full-Scale Design.	May 21, 2004
UNC conducts the Phase 1 full-scale hydraulic fracturing test in Zone 3.	September 2004
UNC installs well SBL-01 in Section 10, Southwest Alluvium.	October 2004
UNC submits the draft SFS for Zone 3 for review.	October 27, 2004
EPA disapproves draft SFS for Zone 3 and directs UNC to perform a Site-wide SFS (SWSFS) consistent with the NCP.	June 24, 2005
Meeting between EPA, UNC, NRC, NMED, and Navajo Nation EPA (NNEPA) to discuss the SWSFS. UNC generally expresses its opposition to the feasibility study process.	August 17, 2005
Meeting between EPA, NNEPA, BIA and NMED in Window Rock, AZ, to discuss feasibility of ICs restricting the use of contaminated ground water.	January 18, 2006
Meeting between EPA and NNEPA in Dallas, TX, to continue discussions on ICs.	March 16, 2006
EPA approves in-situ alkalinity stabilization pilot study for Zone 3.	May 12, 2006
EPA directs UNC to perform the SWSFS in writing, stating that the feasibility study is appropriate and necessary.	June 23, 2006
Meeting between EPA, NNEPA, BIA, and NMED in Albuquerque, NM to continue discussions on ICs.	August 21, 2006
UNC submits the draft List of Preliminary Assembled Remedial Alternatives for the SWSFS.	September 2006
UNC begins the in-situ alkalinity stabilization pilot study in Zone 3. The study is completed in February 2007.	October 2006

TABLE 1A Chronology of Events June 1977 to December 2018 UNC Church Rock Mill Tailings Site, Church Rock, New Mexico	
UNC submits the draft SWSFS, Part 1, Church Rock Remediation Standards Update.	February 2007
UNC submits In-Situ Alkalinity Stabilization Pilot Study Report.	June 2007
EPA disapproves SWSFS, Part 1, Church Rock Remediation Standards Update and requires revision to address written comments.	January 2008
Meeting between EPA, State, NRC, NNEPA and UNC to discuss status of remedial activities. UNC notifies regulatory agencies that pumping of hydraulic fracture wells in Zone 3 was unsuccessful in stopping migration of seepage impacted ground-water. UNC proposes to submit a plan for additional extraction wells for Zone 3.	March 12, 2008
UNC submits summary of hydrogeologic analysis evaluation of groundwater flow and recommended plan for additional extraction wells for interception and recovery of seepage-impacted ground-water in Zone 3.	April 2008
UNC submits white paper on statistics to address some of EPA comments on the SWSFS, Part 1.	May 2008
EPA notifies NRC of approval of UNC's recommendation for additional extraction wells.	June 2008
UNC installs five new extraction wells (the NW-series) in northern Zone 3.	September 2008
EPA issues third Five-Year Review report for the UNC groundwater operable unit.	September 2008
UNC submits calculation of background statistics with comparison values.	October 2008
UNC submits calculation of estimated UCL95 statistics and exposure point concentrations in impacted groundwater.	December 2008
UNC submits to NRC an alternate concentration limits application for Zone 1.	December 2008
Pumping of the NW-series of extraction wells in northern Zone 3 begins. Later in the year the pumping scheme was reorganized to include three of the five wells.	February 2009 and November 2009
EPA issues comment letter on Site-Wide Supplemental Feasibility Part I (Church Rock Remediation Standards Update) and approves Part I (approval later effectively rescinded by EPA comments letters).	February 2009
UNC submits revised Site-Wide Supplemental Feasibility Study Part II.	July 2009
UNC submits hydrogeologic analysis of recent Zone 3 injection testing (new background well NBL-2) in northern Zone 3 and proposal to enhance remediation using one or more injection wells amended with sodium bicarbonate.	December 2009
UNC proposes the location for a pilot injection well in Zone 3.	April 2010
UNC submits a remedial design report on a conceptual approach to enhanced remediation in Zone 3 involving new injection wells combined with existing extraction wells.	May 2010
UNC submits a hydrogeologic analysis of injection testing of Zone 3 well IW-A during July 2010.	August 2010
EPA issues comments letter on revised Site-Wide Supplemental Feasibility Study Part II (UNC document from July 2009).	September 2010
UNC submits an updated baseline human health risk assessment.	March 2011
UNC submits revised Site-Wide Supplemental Feasibility Study Parts I and II.	April 2011
UNC starts injection at well IW-A of site Mill well water amended with alkalinity (sodium bicarbonate).	April 14, 2011
EPA issues comment letter on the draft updated human health risk assessment (March 2011).	July 2011
UNC submits a technical memorandum summarizing two previously submitted reports on Zone 3 tailings seepage sourcing and groundwater recharge, with an information update.	August 2011
EPA issues comment letter on the Site-Wide Supplemental Feasibility Study Part II (July 2009) (in fact, this comment letter addressed Parts I, II, and III).	October 2011
UNC submits provisional responses to EPA comment letter (July 2011) on the draft baseline human health risk assessment (March 2011).	October 2011
UNC submits hydrogeologic assessment of injection at Zone 3 well IW-A through September 2011.	November 2011

TABLE 1A Chronology of Events June 1977 to December 2018 UNC Church Rock Mill Tailings Site, Church Rock, New Mexico	
UNC submits a document requesting discussion and clarification about the EPA comment letter (October 14, 2011) addressing revised Site-Wide Supplemental Feasibility Study Parts I and II (April 2011).	November 2011
By email, UNC provides all agency stakeholders with revisions to the draft updated human health risk assessment (March 2011).	February 2012
EPA risk assessment specialist provides UNC with comments (by email) on the revised draft updated human health risk assessment (February 2012). Followup phone discussion between EPA risk specialist and UNC on April 27, 2012	March 2012 and April 27, 2012
GE submits to NRC a license amendment request for revised groundwater protection standards based on updated background concentrations (statistically calculated background threshold values). The three site hydrostratigraphic units are addressed individually.	April 2012
UNC presents the numeric groundwater hydraulic modeling (with focus on Zone 3) to all agency stakeholders at the annual technical meeting in Albuquerque.	May 14, 2012
UNC makes an operational adjustment of pumping in the northernmost part of Zone 3.	June 2012
UNC submits to EPA: Overview of Draft Attached Tables, Summary Comparisons of Upper Prediction Limits for Parameter Concentrations in Background Groundwater to Site Cleanup Standards and Potential ARARs for All Three Hydrostratigraphic Units at the Church Rock Mill Tailings Site.	June 2012
UNC has their laboratory reduce the reporting limits for beryllium and lead.	July 2012
UNC submits to EPA the Updated Baseline Human Health Risk Assessment – Final, Church Rock Site, Church Rock, New Mexico, United Nuclear Corporation, Gallup, New Mexico.	August 2012
EPA approves the final version of the Updated Baseline Human Health Risk Assessment (August 13, 2012).	September 2012
UNC notifies the agencies that injection of sodium bicarbonate-amended water, in Zone 3 well IW-A, was terminated on June 29, 2012.	October 2012
UNC submits the Groundwater Flow Model of the Church Rock Site and Local Area.	October 2012
UNC submits to NRC Supplemental Information Pertaining to License Amendment Request (April 2012) for Revised Groundwater Protection Standards.	November 2012
UNC sends the agencies an email with discussion of turbidity results from July 2012 and October 2012.	December 2012
EPA issues Record of Decision (ROD) for the Site Surface Soil Operable Unit Alternative 2 preference for disposal of NECR mine waste at UNC Mill Site tailings evaporation ponds under NRC license SUA-1475.	March 2013
EPA Office of Research and Development (ORD) issues technical memorandum on the background ground water conditions in the SWA and Zones 1 and 3 of UNC Site and the proposed cleanup and compliance monitoring levels for COPCs using the statistically-based 95 percent upper prediction limits (UPL95s) (also known as "Overview of Draft Attached Tables, Summary Comparisons of Upper Prediction Limits for Parameter Concentrations in Background Groundwater to Site Cleanup Standards and Potential ARARs for All Three Hydrostratigraphic Units at the Church Rock Mill Tailings Site.")	March 2013
DOE issues comments to NRC regarding the April 2012 UNC License Amendment Request for Revised Groundwater Protection Standards Based on Updated Background Concentrations.	April 2013
NRC issues response to DOE comments on the April 2012 UNC License Amendment Request for Revised Groundwater Protection Standards Based on Updated Background Concentrations.	June 2013
NRC issues Request for Additional Information (RAI) pertaining to License Amendment Request (April 2012) for Revised Groundwater Protection Standards.	June 2013
EPA issues fourth Five-Year Review report for the UNC Superfund Site	September 2013
NNEPA formally requests that UNC locate, permit, drill, construct and operate sentinel wells on north of the UNC Church Rock Mill Site Section 36 boundary.	October 2013
UNC submits to NRC a response to the RAI pertaining to License Amendment Request (April 2012) for Revised Groundwater Protection Standards.	January 2014
UNC submits to NRC a revised groundwater flow model report.	June 2014

TABLE 1A Chronology of Events June 1977 to December 2018 UNC Church Rock Mill Tailings Site, Church Rock, New Mexico	
NRC issued a draft Environmental Assessment (EA) pertaining to the License Amendment Request (April 2012) for Revised Groundwater Protection Standards for review by other governmental agencies.	August 2014
UNC submits proposed sentinel well locations north of the UNC Church Rock Mill Site Section 36 boundary.	September 2014
EPA and NMED issue comments to NRC regarding August 2014 EA pertaining to the License Amendment Request (April 2012) for Revised Groundwater Protection.	October 2014
UNC submits proposed potential cleanup levels to EPA: updated Overview of Draft Attached Tables, Summary Comparisons of Upper Prediction Limits for Parameter Concentrations in Background Groundwater to Site Cleanup Standards and Potential ARARs for All Three Hydrostratigraphic Units at the Church Rock Mill Tailings Site (March 29, 2015).	March 2015
NRC issues License Amendment No. 52 on April 9, 2015 which approves the April 2012 license amendment request related to revised groundwater protection standards (based on updated statistically calculated background threshold values). The three site hydrostratigraphic units are addressed individually.	April 2015
EPA indicates that UNC may proceed with the SWSFS using the March 2015 proposed potential cleanup levels.	September 2015
GE submits to NRC a license amendment request (October 22, 2015) to update the license for progress and changes that have taken place with respect to corrective action program and the on-going re-design and environmental review of the tailings disposal impoundment to incorporate mine spoil. Some editorial and typographical corrections are also proposed (including corrections to License standards). This license amendment request was intended to withdraw and replace a previous request dated January 22, 2015.	October 2015
UNC submits to EPA a letter describing how the proposed monitoring well network on the Navajo Reservation will be used to collect the hydrogeochemical information needed to establish areas where future administrative controls would be applied, in support of a future remedy.	April 2016
EPA and the Navajo Nation approve the proposed monitoring well locations on the Navajo Reservation and agree that UNC that should proceed with the plan to permit and install monitoring wells north of the Section 36 boundary on the Navajo Reservation (email from Janet Brooks to Roy Blickwedel, July 27, 2016).	July 2016
EPA requests quarterly reporting of northern Zone 3 monitoring well sampling, starting with October 2016 monitoring event.	August 2016
GE/UNC requests (December 8, 2016, corrected February 13, 2017) to amend previous license amendment request that was submitted on October 22, 2015. The amendment is to remove well GW 2 as a POC well for the Southwest Alluvium. All other aspects of the October 22, 2015 request remain the same.	February 2017
UNC submits to the Navajo Nation Department of Water Resources (Technical, Construction and Operations Branch [TCOB]), a preliminary well drilling permit application on April 25th, 2017, for the proposed monitoring wells on the Navajo Reservation. The permitting process is ongoing.	April 2017
EPA issues the fifth Five-Year Review report for the UNC Superfund Site.	September 2018

TABLE 1B

Southwest Alluvium Performance Monitoring Program, 2018 Operating Year
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well	Use[1]	Water Level	Water Quality	NRC POC	Purpose
509 D	Monitor	X	X	Y	Seepage extent
624	Monitor	X	X		Downgradient background, seepage extent
627	Monitor	X	X		Downgradient background, seepage extent
632	Monitor	X	X	Y	Seepage extent
801[2]	Pumping (idled)	X	X		Seepage and saturation extent
802	Pumping (idled)	X	X		Seepage and saturation extent
803	Pumping (idled)	X	X		Seepage and saturation extent
805	Monitor	X			Water level only
807	Monitor	X			Water level only
808[3]	Pumping (idled)	X	X		Seepage extent
EPA 23	Monitor	X	X	Y	Problematic completion
EPA 25	Monitor	X	X		Downgradient background, seepage extent
EPA 28	Monitor	X	X	Y	Seepage extent
GW 1	Monitor	X	X	Y	Seepage extent
GW 2[4]	Monitor	X	X	Y	Seepage extent
GW 3[4]	Monitor	X	X	Y	Downgradient background, seepage extent
	Total	16	14		

Eliminated From Monitoring					Reason for Elimination
GW 4	X	X			Dry
EPA 22A				Y	Dry
29A					Dry
639					Dry
642					Dry
644					Dry
645					Dry
804					Not needed, use 632
806					Not needed, use 805
EPA 27					Dry

Notes:

1 Pumping wells turned off in January 2001 after final baseline samples were collected. Well 801 is the exception, see Note 2.

2 Well 801 was turned off at the end of July 1999 because it met decommissioning criteria. Sample collection ceased after the first quarter 2000. Well 801 water quality is included in the test program, therefore sampling recommenced January 2001 and has continued through 2018.

3 Well 808 was not included in the Performance Monitoring Program prior to the NA Test, therefore no data are available prior to January 2001.

4 Wells GW 2 and GW 3 are very close to the Pipeline Arroyo canyon and can no longer be accessed due to safety concerns.

TABLE 2

Detected Constituents in Southwest Alluvium, October 2018

United Nuclear Corporation, Church Rock Site

Church Rock, New Mexico

Chemical Name	License NRC Standard	EPA Cleanup Level	Unit	0509 D	0624	0627	0632	0801	0802	0803	0808	EPA 23	EPA 25	EPA 28	EPA 28 FD	GW 1	SBL-01
			Section #	2	3	3	2	2	2	2	2	2	3	3	3	3	10
ALUMINUM	-	5	mg/l	0.04	0.3					0.04	0.03						0.52
AMMONIA (AS N)	-	-	mg/l					3.3 D		0.28	1.18	0.38					
BICARBONATE (HCO3)	-	-	mg/l	2330	1600	570	1730	1520	2010	1570	1870	1300	1400	416	424	1780	437
CALCIUM	-	-	mg/l	845	697	540	572	561	652	627	643	675	821	499	499	683	478
CHLORIDE	-	250	mg/l	338 D	217 D	34 D	242 D	218 D	192 D	154 D	179 D	123 D	150 D	99 D	101 D	242 D	78 D
CHLOROFORM	80	80	ug/l				0.58		1.6							0.52	
COBALT	-	0.05	mg/l	0.013								0.01					0.029
GROSS ALPHA	15	15	pci/l	1.7	0.9	3.1	1.8		1.2			1.3		1.2	1.2		1.1
LEAD	0.07	0.07	mg/l							0.001	0.001						
MAGNESIUM	-	-	mg/l	354	428	234	724	696	700	624	635	379	257	442	433	515	1250
MANGANESE	-	2.1	mg/l	3.74	0.168	0.102	3.12	6.12	1.32	3.55	2.33	6.17	0.478	0.493	0.41	0.033	3.78
MOLYBDENUM	-	1	mg/l	0.002				0.001				0.001					0.001
NICKEL	0.078	0.2	mg/l	0.006			0.014	0.015	0.007	0.006				0.009	0.008		0.081
NITRATE (NO3)	-	536.6	mg/l	9.75 D	75.0 D	79.0 D	41.5 D	55 D	75 D	29.1 D	13.5 D	0.03	66.0 D	6.00 D	6.40 D	74 D	36.6 D
PH (FIELD)	-	-	su	6.5	6.59	6.96	6.52	6.69	6.56	6.6	6.58	6.74	6.74	6.96	6.97	6.73	6.49
PH (LAB)	-	-	su	6.53 H	6.64 H	6.95 H	6.53 H	6.64 H	6.56 H	6.58 H	6.58 H	6.68 H	6.82 H	6.87 H	6.91 H	6.66 H	6.80 H
POTASSIUM	-	-	mg/l	13	6	6	10	12	5	12	10	11	9	12	11	9	13
RADIUM-226	-	-	pci/l	0.3	0.3	0.3	0.6	0.6	0.4		0.3	0.5		0.6	0.6		0.5
RADIUM-228	-	-	pci/l	2.4	2.7	1.6	2.7		2.2	2.3	1.7		1.9				2.7
RADIUM 226 & 228	8.2	8.2	pci/l	2.7	3	1.9	3.3	0.6	2.6	2.3	2	0.5	1.9	0.6	0.6	0	3.2
SODIUM	-	-	mg/l	412 D	322 D	374 D	369 D	338 D	320 D	251 D	348 D	151 D	225 D	260 D	247 D	386 D	299 D
SULFATE (SO4)	-	5815	mg/l	2180 D	2310 D	2340 D	3480 D	3500 D	3170 D	3190 D	3290 D	2420 D	1990 D	3210 D	3170 D	2740 D	6150 D
TOTAL DISSOLVED SOLIDS (LAB)	-	10376	mg/l	5680 D	5360 D	4250 D	7000 D	6720 D	6870 D	6210 D	6520 D	4770 D	4540 D	5070 D	5040 D	6140 D	9350 D
TOTAL TRIHALOMETHANES	80	80	ug/l				0.58		1.6							0.52	
URANIUM	0.3	-	mg/l	0.237	0.0407	0.0198	0.0693	0.0366	0.133	0.068	0.0739	0.0313	0.126	0.0189	0.0204	0.0942	0.0089

Blank cells indicate that the analyte was not detected

Shaded values exceed the listed action level

D indicates that the sample was diluted for analysis

H indicates that the analysis was performed beyond the analytical method holding time

FD indicates a field duplicate sample

TABLE 3

Southwest Alluvium Saturated Thickness, October 2018

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well	Water Level Measurement Date	SW Alluvium Unsaturated Thickness	SW Alluvium Saturated Thickness	SW Alluvium Percentage Saturated
0509 D	10/1/2018	83.28	26.72	24%
0624	10/2/2018	55.80	19.20	26%
0627	10/2/2018	62.17	8.83	12%
0632	10/1/2018	48.45	18.55	28%
0801	10/1/2018	54.12	6.38	11%
0802	10/1/2018	51.87	29.63	36%
0803	10/1/2018	67.17	50.83	43%
0805	10/11/2018	54.41	65.59	55%
0807	10/11/2018	60.27	39.73	40%
0808	10/1/2018	53.63	78.37	59%
EPA 23	10/1/2018	58.39	61.61	51%
EPA 25	10/2/2018	56.02	13.98	20%
EPA 28	10/1/2018	65.42	12.58	16%
GW 1	10/1/2018	65.32	11.68	15%
GW 2	NM	-	-	-
GW 3	NM	-	-	-
SBL-01	10/2/2018	49.57	15.43	24%

TABLE 4

Summary of Operational Data
Southwest Alluvium Extraction Wells 1989 to 2001
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well No.	Annual Average Pumping Rate (gallons per minute)												
	1990 (1)	1991 (2)	1992 (3)	1993 (4)	1994 (5)	1995 (6)	1996 (7)	1997 (8)	1998 (9)	1999 (10)	2000 (11)	2001 (12)	1990-2001
801 (13)	1.2	0.5	0.4	0.2	0.2	0.1	0.1	0.1	0.08	0.08	0.00	0.00	0.25
802	11.1	12.5	11.9	9.0	9.8	9.7	9.1	10.1	11.02	9.62	9.31	5.80	9.91
803	2.0	2.6	2.5	3.0	3.2	3.5	3.1	2.9	3.84	3.56	3.83	3.68	3.14
808 (14)		10.0	15.5	19.9	15.6	12.3	12.2	7.2	4.34	3.50	2.50	3.35	9.67
Total Pumping Rate	14.3	25.6	30.3	32.1	28.8	25.6	24.5	20.3	19.29	16.76	15.64	11.94	22.98
Volume Pumped (millions of gallons) (15)	7.4	12.4	17.2	18.1	15.7	12.9	12.2	9.2	9.0	7.5	7.7	1.7	131.0

Notes:

1. Average pumping rate calculated for the period between October 13, 1989, and October 12, 1990.
2. Average pumping rate calculated for the period between October 13, 1990, and October 11, 1991, except Well 808, which calculated for the period between June 26, 1991 (i.e., well startup) and October 11, 1991.
3. Average pumping rate calculated for the period between October 12, 1991, and October 8, 1992.
4. Average pumping rate calculated for the period between October 9, 1992, and October 8, 1993.
5. Average pumping rate calculated for the period between October 9, 1993, and October 14, 1994.
6. Average pumping rate calculated for the period between October 15, 1994, and September 29, 1995.
7. Average pumping rate calculated for the period between September 30, 1995, and September 27, 1996.
8. Average pumping rate calculated for the period between September 28, 1996, and September 26, 1997.
9. Average pumping rate calculated for the period between September 27, 1997, and September 25, 1998.
10 . Average pumping rate calculated for the period between October 02, 1998, and September 27, 1999.
11. Average pumping rate calculated for the period between September 28, 1999, and September 29, 2000.
12. Average pumping rate calculated for the period between September 30, 2000, and January 12, 2001.
13. Well 801 decommissioned at the end of July 1999.
14. Well 808 began operation on June 26, 1991.
15. Data obtained from system flowmeter.

Source: Earth Tech, December 2002, Figure 2.1

TABLE 5
Southwest Alluvium Groundwater Velocities, October 2018
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well Pair 805 and 624

Groundwater Elevations: 6856.38 (Well 805) and 6843.40 (Well 624) ft amsl
Separation Distance: 1902 ft
Average Linear Horizontal Hydraulic Gradient: 0.0068
Velocity 1 = 65 ft/yr
Velocity 2 = 50 ft/yr
Average Velocity = 59 ft/yr

Well Pair 805 and 627

Groundwater Elevations: 6856.38 (Well 805) and 6830.29 (Well 627) ft amsl
Separation Distance: 3203 ft
Average Linear Horizontal Hydraulic Gradient: 0.0081
Velocity 1 = 78 ft/yr
Velocity 2 = 60 ft/yr
Average Velocity = 69 ft/yr

Well Pair 624 and SBL 1

Groundwater Elevations: 6843.40 (Well 624) and 6845.04 (Well SBL 1) ft amsl
Separation Distance: 500 ft
Average Linear Horizontal Hydraulic Gradient: -0.0033
~~*Velocity 1 = -31 ft/yr*~~
~~*Velocity 2 = -24 ft/yr*~~
~~*Average Velocity = -27 ft/yr*~~

Darcy seepage velocity calculation input values:
- Mean hydraulic conductivity used = 2.5×10^{-3} cm/s (based on groundwater flow model calibration for the for the Southwest Alluvium (Chester Engineers, 2012g)).
- Range of effective porosities = 27% (velocity 1) to 35% (velocity 2) (Canonie, 1989b; Earth Tech, 2002c).

TABLE 6
Predicted Performance of Southwest Alluvium Natural Attenuation, 2018
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Constituent	Will Standards Be Met?			Remarks
	Section 2	Section 3	Section 10	
Manganese	No	Yes	No	Not regulated by NRC. Revised EPA standard lower than previous standard. Section 2 includes onsite seepage impact; Section 3 includes offsite seepage impact with Mn attenuated and known background water with Mn below EPA standard; Section 10 includes advancing front of seepage impact with Mn below EPA standard but Mn above EPA standard in background Well SBL 1 (see Table 2 and Table A.1 in Appendix A).
Sulfate	Yes	Yes	No	Not regulated by NRC. Current EPA standard higher than previous standard. Seepage impact area sulfate concentrations lower than revised EPA standard; Section 10 background waters typically characterized by exceedances unrelated to seepage impact; highest sulfate concentrations occur in background Well SBL 1 in Section 10 (see Figures 7, 9, and 16).
Chloride	No	Yes?	Yes	Not regulated by NRC. Section 2 includes onsite seepage impact with revised EPA standard exceedances at two locations in 2018 (Wells 509 D and 632). Section 3 includes offsite seepage impact with one slight exceedance in 2018 (GW 1). Section 10 includes advancing front of seepage impact with no exceedances at background Well SBL 1.
TDS	Yes	Yes	Yes	Not regulated by NRC. Revised EPA standard higher than previous standard. Governed by sulfate concentration; highest TDS concentrations occur in background Well SBL 1 and, historically, in impacted Well GW 2* (see Figure 17).
Metals	Yes	Yes	No	Attenuation by neutralization and adsorption. Section 2 includes onsite seepage impact with no exceedances; Section 3 includes offsite seepage impact and known background water with no exceedances; Section 10 includes advancing front of seepage impact with no exceedances, but small exceedances of NRC License standard for nickel in background Well SBL 1 continued during 2018 (see Table 2).
Radionuclides	Yes	Yes?	Yes	Attenuation by neutralization and adsorption; uranium exceedances in GW 3* (Section 3, July 2012 and January 2013-July 2015) are associated with the smallest saturated thickness (July 2015 = 2.07 ft (4%)) in the Southwest Alluvium. GW 3 is projected to have 0% saturated thickness in 2018. One unusual exceedance of at NRC/revised EPA Pb-210 standard at Well 801 (April 2018) exceeded NRC/revised EPA within Section 2. Only 12 previous exceedances at SWA locations and one previous exceedances at Well 801 (January 1997).
TTHMs	Yes	Yes	Yes	Attenuated by degradation, dilution, dispersion. No exceedances of NRC/EPA standard.

Notes:
NRC License GWPSs and EPA cleanup standards have been revised based on background statistical analysis (i.e., UPL95s).
* Wells GW 2 and GW 3 not sampled beginning October 2015; they are near the edge of the Pipeline Arroyo canyon and can no longer be safely accessed. GW 3 also no longer meets the low flow sampling specifications and cannot be sampled reliably.

TABLE 7

Change in Zone 3 Saturated Thickness from 1989 to 2018

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well Number[1]	Saturated Thickness		Change (feet)	Change
	3rd Quarter 1989	4th Quarter 2018		
402	--	7.36	--	--
420	56.3	0.00	-56.3	-100.00%
424	--	10.39	--	--
446[2]	--	10.03	--	--
504 B	40.1	0.00	-40.1	-100.00%
517	42.7	7.02	-35.7	-83.54%
613[3]	67.2	18.46	-48.7	-72.53%
EPA 09	8.1	2.98	-5.1	-63.16%
EPA 13	24.8	5.53	-19.3	-77.73%
EPA 14	76.3	18.15	-58.1	-76.21%
701	46.1	15.05	-31.0	-67.35%
702	24.1	7.33	-16.8	-69.59%
703	32.6	17.60	-15.0	-46.01%
705	--	--	--	--
706	--	13.20	--	--
707	58.8	7.64	-51.2	-87.01%
708	49.8	9.13	-40.7	-81.66%
709	56.1	8.82	-47.3	-84.29%
710	45.5	8.31	-37.2	-81.73%
711	43.7	15.80	-27.9	-63.84%
712	39.1	3.63	-35.5	-90.70%
713	34.2	6.97	-27.2	-79.63%
714[4]	50.1	10.80	-39.3	-78.45%
715[4]	47.6	6.01	-41.6	-87.37%
716[4]	58.3	11.88	-46.4	-79.63%
717[4]	57.6	13.28	-44.3	-76.94%
718[4]	51.1	10.86	-40.2	-78.75%
719[4]	39.9	4.25	-35.6	-89.34%
720[4]	33.1	0.00	-33.1	-100.00%
NBL-01[5]	--	dry	--	--
501 B[6]	20.2	--	--	--
411[6]	62.5	--	--	--
502 B[6]	48.5	--	--	--
518[6]	37.2	--	--	--
EPA 01[6]	14.7	--	--	--
EPA 03[6]	8.3	--	--	--
EPA 11[6]	30.8	--	--	--
EPA 12[6]	10.7	--	--	--
EPA 15[6]	60.8	--	--	--
EPA 17[6]	1.4	--	--	--
EPA 18[6]	2.5	--	--	--
Average	37.3	8.95	-36.4	-80%

Notes:

[1] Wells 9 D and 106 D were not included because they appear to be completed above the bottom of Zone 3. Measurements of saturated thickness in these wells may be less than actual conditions. Well 126 was not included because it was completed above the bottom of Zone 3. Measurements of saturated thickness in this well are less than actual conditions.
Wells 600, 610 and 672 were not included because they were used solely as pumping wells, therefore no water level data are available.
Well 608 was not included because no water level data were available in 1989 and the last water level measurement was in February 2000.

[2] Saturated thickness estimates based on Well 446 water level measurements are unreliable; the water level is likely below the bottom of the screened interval (within a section of blank casing) and it is difficult to measure due to the presence of a floating natural oil lens.

[3] Water level for Well 613 measured in 1983 before pumping started. Water level data for 1989 are not available because well was pumping.

[4] Water levels for the Stage II wells were measured June 1991 when wells were installed. Not included in 1989 average saturated thickness calculation.

[5] Well NBL-01 installed in July 2001 and first water level measured in August 2001.

[6] Wells are not currently monitored. See Table 9 for additional information regarding the status of each well

Shading indicates saturated thickness greater than 25 feet.

"--" indicates that there is no data available.

TABLE 8

Estimated Mass Removal by Extraction Well Pumping in Zone 3, December 2017 Through November 2018
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well	Water Pumped (gallons)	SO4 (kg)	NO3 as N (kg)	Chloroform (g)	Al (kg)	As (g)	Be (g)	Co (g)	Pb (g)	Mn (kg)	Mo (g)	Ni (g)	U (g)	Total Radium (mci)	Pb-210 (mci)	Gross Alpha (mci)
RW-11	93,424	1,308	0	0.1	0.0	1	0	126	0	2	47	126	22	8	0.39	4
RW-16	74,814	1,560	1.6	0.2	78	0.1	53	320	12	5	1	357	209.8	5	0.51	4
RW-17	96,323	1,670	0.01	0.1	1	0.7	1	93	1	2	149	124	16	7	0.18	3
PB-2	0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0.00	0
RW-A	39,413	641	0	0	0.1	0.1	0	68	0	1	7	71	3	5	0.07	3
NW-1	0	0	0	0	0.0	0.0	0	0	0	0	0	0	0	0	0.00	0
NW-2	81,828	1,236	0.08	0.1	2.8	0.2	6	251	20	3	15	350	33	5	0.15	3
NW-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NW-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NW-5	134,147	2,026	0	0	5	0	10	411	32	4	25	574	54	8	0	4
Total	519,948	8,442	2	0.42	87	2.1	71	1,269	65	17	244	1,602	339	37	1.56	21

Notes:

Pumping data reported for 11/30/17 through 11/30/2018

Wells are located on Figure 38 of the *2018 Annual Review Report* .

Wells RW-12, RW-13, and RW-15 were not pumped, because of negligible capacity.

Wells PB 2, NW 1, NW 3, and NW 4 were not pumped.

Units for radionuclides (mci) are not mass units proper; mci are milli-Curies, or thousandths of Curies.

In developing this table, masses were estimated from analyses of October 2018 samples from RW-11 and RW-A. Masses for RW-16 and RW-17 were estimated from concentrations in samples from nearby wells 717 and 719. Masses in the NW-series wells were estimated from concentrations in the 2013 sample from PB-03

Nonradiological nondetects were assigned values of one-half the reporting limit.

Radiological results were assigned as reported (even if negative).

TABLE 9
Zone 3 Performance Monitoring Program, 2018 Operating Year
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well	Water Level	Water Quality	NRC POC	Purpose
Continue Monitoring				
420	X	X		Postmining-pretailings background, track plume.
711	X	X	Y	Track saturation and plume, replace 502 B based on results of low flow purge testing performed in January 2000.
504 B	X	X		Track saturation and plume, extensive data set.
517	X	X	Y	Track plume, extensive data set.
EPA 9	X			Extent of saturation, water quality not necessary.
EPA 13	X	X		Extent of saturation. Water quality added 2nd quarter 2001.
EPA 14	X	X		Postmining-pretailings background, track plume.
702	X			Water level only, track saturation.
710	X			Water level only.
712	X			Water level only.
713	X			Water level only.
714	X			Water level only.
613	X	X	Y	Extensive data set, track saturation and source.
701	X			Water level only (decommissioned pumper).
706	X			Water level only (decommissioned pumper).
707	X			Water level only (decommissioned pumper).
708	X	X	Y	Added to program 2nd quarter 2001.
717	X	X		Water level. Water quality added 2nd quarter 2001.
719	X	X		Water level. Water quality added 2nd quarter 2001.
Additional Wells, Not Included In Original Performance Monitoring Program				
402	X			Long-term water level for migration path.
424	X			Long-term water level for migration path.
446	X			Long-term water level for migration path.
Total	22	10		

Eliminated From Monitoring				Reason For Elimination
9 D				Dry
106 D				Dry
411				Oil, cannot get water level or sample.
501 B			Y	Dry
EPA 1				Dry
EPA 3			Y	Dry
EPA 11				Unuseable since 1990 - water level below pump, pump cemented in well.
EPA 12				Dry
EPA 15				Dry
EPA 17				Dry
EPA 18				Dry
126				Dry
502 B				Failed low-flow test, use 711
518			Y	Failed low-flow test, use 517
608				Not needed (formerly water level only)
703				Not needed (formerly water level only)
715				Not needed (formerly water level only)
709				Not needed (decommissioned pumper)
716				Not needed (pumper)
718				Not needed (pumper)
720				Not needed (decommissioned pumper)

Notes:
NRC POC = Nuclear Regulatory Commission Point of Compliance well
Well NBL 1 was drilled and installed June 2001. Water level and water quality to track downgradient extent of seepage.
Well NBL 1 is not a formal requirement of the performance monitoring program, but it was also monitored for both water level and water quality until it was dewatered in 2014. It has been dry since that time.
Source: Earth Tech, December 2002, Table 3.2

TABLE 10

Zone 3 Saturated Thickness, October 2018

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well	Water Level Measurement Date	Zone 3 Unsaturated Thickness	Zone 3 Saturated Thickness	Zone 3 Percentage Saturated
0402	10/11/2018	55.64	7.36	12%
0420	10/8/2018	51.00	0.00	0%
0424	10/11/2018	62.61	10.39	14%
446[3]	10/11/2018	54.97	10.03	15%
0504 B	10/11/2018	--[1]	<1.73[1]	--[1]
0517	10/8/2018	54.98	7.02	11%
0613	10/8/2018	49.54	18.46	27%
0701	10/11/2018	48.95	15.05	24%
0702	10/11/2018	73.67	7.33	9%
0703	10/11/2018	74.40	17.60	19%
0706	10/11/2018	64.80	13.20	17%
0707	10/11/2018	80.36	7.64	9%
0708	10/8/2018	75.87	9.13	11%
0709	10/11/2018	68.18	8.82	11%
0710	10/11/2018	72.69	8.31	10%
0711	10/8/2018	69.20	15.80	19%
0712	10/11/2018	82.37	3.63	4%
0713	10/11/2018	66.03	6.97	10%
0714	10/11/2018	27.20	10.80	28%
0715	10/11/2018	28.99	6.01	17%
0716	10/11/2018	52.12	11.88	19%
0717	10/8/2018	57.72	13.28	19%
0718	10/11/2018	36.14	10.86	23%
0719	10/9/2018	40.75	4.25	9%
EPA 09	10/3/2018	47.02	2.98	6%
EPA 13	10/8/2018	58.47	5.53	9%
EPA 14	10/9/2018	54.85	18.15	25%
MW-2	10/11/2018	51.17	9.26	15%
MW-3	10/11/2018	54.79	6.13	10%
MW-4	--[4]	--	<2[1]	--
MW-5	--[4]	--	<2[1]	--
MW-6	10/10/2018	--[1]	--[1]	--[1]
MW-7	10/9/2018	45.86	8.61	16%
NBL-01	10/11//2018	--	--	--[2]
NBL-02	10/9/2018	64.11	13.46	17%
NW-1	10/10/2018	42.63	1.66	4%
NW-2	10/10/2018	45.02	6.10	12%
NW-3	10/10/2018	46.09	11.72	20%
NW-4	10/10/2018	44.29	6.07	12%
NW-5	10/10/2018	45.80	12.21	21%
PB-02	10/10/2018	--[1]	<2[1]	--[1]
PB-03	10/10/2018	--[1]	<2[1]	--[1]
PB-04	10/10/2018	36.60	0.40	1%
RW-11	10/10/2018	54.73	7.11	11%
RW-15	--[4]	--	--	--
RW-16	10/11/2018	55.39	7.71	12%
RW-17	10/11/2018	67.64	5.59	8%
RW-A	10/10/2018	59.31	8.56	13%
Z3 M-01	10/11/2018	42.94	0.24	1%
Z3 M-02	10/11/2018	43.85	2.44	5%
IW-A	10/10/2018	46.51	1.20	3%

[1] Dry well

[2] Obstructed well (i.e., water level dropped below sediment at well base)

[3] Well 446 water level is suspect and is likely below the bottom of the screened interval (within a section of blank casing). Actual local water level likely significantly lower. Measured value represents depth to floating lens of crude oil.

[4] Not Measured

TABLE 11

Zone 3 Field Parameter Measurements of Tracking Wells Through October 2018

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

	Bicarbonate (mg/L)							Conductivity (umhos/cm)							pH (s.u.)							Chloride (mg/L)						
Date	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A
Oct-02	0	58	194	224	330	NA	NA	5,010	4,040	3,730	3,670	3,160	NA	NA	5.06	7.09	7.10	7.10	7.18	NA	NA	NA	25.3	23.8	113.0	NA	NA	NA
Nov-02	0	41	188	299	285	NA	NA	4,930	3,080	2,860	2,510	3,120	NA	NA	5.30	5.95	6.47	6.60	6.51	NA	NA	14.0	26.5	24.3	23.8	21.0	NA	NA
Dec-02	22.9	57	178	283	NA	NA	NA	5,040	4,120	3,950	3,330	NA	NA	NA	5.40	5.75	6.40	6.68	NA	NA	NA	22.9	26.2	23.2	25.7	NA	NA	NA
Jan-03	0	34	148	239	311	NA	NA	5,180	3,930	3,716	3,460	3,300	NA	NA	5.54	4.97	6.92	6.41	6.43	NA	NA	NA	NA	22.9	22.8	NA	NA	NA
Feb-03	0	58	193	324	328	NA	NA	3,620	2,910	2,660	2,570	2,300	NA	NA	3.52	5.57	6.96	6.92	6.53	NA	NA	26.7	30.1	30.4	28.5	21.5	NA	NA
Mar-03	NA	60	188	311	326	NA	NA	4,000	3,090	2,890	2,680	2,500	NA	NA	3.49	5.59	6.71	6.95	6.73	NA	NA	26.4	30.1	29.7	29.7	22.1	NA	NA
Apr-03	NA	34	172	310	321	NA	NA	4,210	4,460	4,220	3,820	2,650	NA	NA	5.14	5.46	5.94	6.26	6.87	NA	NA	26.6	30.5	30.0	30.1	21.6	NA	NA
May-03	0	34	167	293	322	NA	NA	5,510	4,460	4,210	3,820	3,390	NA	NA	5.01	5.36	5.99	6.31	6.37	NA	NA	28.0	31.0	30.2	31.9	32.7	NA	NA
Jun-03	0	21	129	267	316	NA	NA	5,470	4,480	4,060	3,820	3,380	NA	NA	4.28	5.15	6.17	6.20	6.36	NA	NA	27.7	30.8	29.6	30.6	28.0	NA	NA
Jul-03	NA	32	126	257	311	NA	NA	5,480	4,560	4,330	3,920	3,500	NA	NA	5.35	5.28	5.85	6.32	6.29	NA	NA	26.5	30.6	29.7	31.1	25.8	NA	NA
Aug-03	NA	5	100	234	307	NA	NA	5,210	4,280	3,960	3,630	3,230	NA	NA	5.14	5.18	5.76	6.18	6.28	NA	NA	27.0	30.4	29.7	31.1	23.1	NA	NA
Sep-03	NA	7	91	218	295	NA	NA	5,260	4,400	4,160	3,770	3,340	NA	NA	4.68	5.23	5.79	6.28	6.39	NA	NA	28.0	30.5	29.3	31.5	26.7	NA	NA
Oct-03	NA	0	65	211	295	NA	NA	5,360	4,450	4,210	3,860	3,410	NA	NA	5.48	5.18	5.81	6.34	6.41	NA	NA	27.7	21.0	30.0	32.7	26.8	NA	NA
Nov-03	NA	0	73	197	285	NA	NA	5,290	4,510	4,210	3,880	3,490	NA	NA	5.09	5.25	5.81	6.24	6.42	NA	NA	27.3	30.6	30.2	32.1	24.8	NA	NA
Dec-03	NA	NA	41	166	265	NA	NA	5,370	4,540	4,290	3,910	3,510	NA	NA	4.41	5.14	5.77	6.76	6.48	NA	NA	27.7	30.2	29.8	31.5	25.2	NA	NA
Jan-04	NA	NA	73	194	327	NA	NA	5,340	4,610	4,310	4,030	3,550	NA	NA	5.39	5.16	5.82	7.51	6.50	NA	NA	32.5	30.5	29.5	32.6	26.8	NA	NA
Feb-04	NA	NA	50	190	323	NA	NA	5,410	4,630	4,260	3,970	3,590	NA	NA	3.40	3.81	5.99	6.25	6.40	NA	NA	28.0	30.1	30.3	32.7	26.6	NA	NA
Mar-04	NA	15	48	179	316	NA	NA	5,560	4,730	4,500	4,130	3,780	NA	NA	3.89	4.75	5.70	6.31	6.29	NA	NA	27.5	30.1	30.2	33.3	25.9	NA	NA
Apr-04	NA	15	48	174	315	NA	NA	5,370	4,560	4,380	4,010	3,630	NA	NA	5.36	5.08	5.52	6.03	6.34	NA	NA	28.1	32.1	32.3	36.2	31.1	NA	NA
May-04	NA	0	27	166	312	NA	NA	6,190	4,390	4,160	3,870	3,510	NA	NA	3.26	5.02	5.34	5.88	6.23	NA	NA	28.4	33.2	32.8	38.1	31.9	NA	NA
Jun-04	NA	0	22	152	294	NA	NA	5,510	4,530	4,400	4,040	3,750	NA	NA	4.48	4.92	5.46	6.05	6.40	NA	NA	28.2	32.6	32.9	37.7	34.1	NA	NA
Jul-04	NA	0	20	140	274	NA	NA	5,450	4,510	4,420	4,000	3,740	NA	NA	5.48	5.04	5.58	6.05	6.45	NA	NA	27.8	31.9	32.8	36.9	34.1	NA	NA
Aug-04	NA	0	17	124	272	NA	NA	5,500	4,450	4,380	4,040	3,710	NA	NA	3.77	4.26	5.45	5.98	6.39	NA	NA	28.3	31.0	32.3	36.2	33.7	NA	NA
Sep-04	0	0	20	117	251	NA	NA	5,480	4,500	4,430	4,030	3,790	NA	NA	4.04	4.46	5.48	6.05	6.45	NA	NA	28.5	30.9	32.5	36.0	34.0	NA	NA
Oct-04	0	0	18	102	245	NA	NA	5,520	4,540	4,560	4,110	3,940	NA	NA	5.56	5.15	5.62	6.08	6.47	NA	NA	27.8	31.5	32.0	30.2	33.2	NA	NA
Nov-04	0	0	17	98	245	NA	NA	5,370	4,400	4,340	3,950	3,840	NA	NA	4.46	4.23	5.47	5.99	6.37	NA	NA	28.8	31.4	32.3	35.6	32.0	NA	NA
Dec-04	0	0	13	87	207	NA	NA	5,290	4,340	4,290	3,920	3,790	NA	NA	4.46	4.28	5.44	5.95	6.36	NA	NA	28.3	31.2	31.0	34.0	30.0	NA	NA
Jan-05	11	0	32	79	198	NA	NA	5,700	4,610	4,520	4,110	4,080	NA	NA	5.31	3.92	5.46	6.03	6.29	NA	NA	29.1	31.3	31.3	33.8	34.2	NA	NA
Feb-05	0	0	7	68	196	NA	NA	5,680	4,720	4,550	4,130	3,980	NA	NA	3.92	3.24	5.31	5.98	6.37	NA	NA	28.0	31.5	31.3	33.4	30.0	NA	NA
Mar-05	0	0	0	60	169	NA	NA	5,540	4,510	4,350	3,990	3,960	NA	NA	3.84	3.72	5.32	5.93	6.27	NA	NA	24.5	31.3	32.0	33.7	35.2	NA	NA
Apr-05	8	0	29	70	154	NA	NA	5,350	4,300	4,340	3,980	3,890	NA	NA	4.46	4.25	5.56	5.88	6.31	NA	NA	27.8	32.4	32.2	34.0	35.1	NA	NA
May-05	0	0	0	67	150	NA	NA	5,300	4,290	4,170	3,840	3,810	NA	NA	4.33	3.78	4.53	5.85	6.30	NA	NA	28.5	32.6	30.6	33.4	34.6	NA	NA
Jun-05	0	0	0	65	138	NA	NA	5,400	4,330	4,280	3,980	3,910	NA	NA	4.06	3.93	4.63	5.77	6.15	NA	NA	28.1	32.1	31.0	33.6	34.7	NA	NA
Jul-05	0	0	0	67	123	NA	NA	5,020	4,150	4,100	3,780	3,640	NA	NA	5.10	3.55	4.04	5.58	5.88	NA	NA	27.9	31.2	31.9	33.1	34.3	NA	NA
Aug-05	0	0	0	57	122	NA	NA	5,270	4,320	4,360	3,880	3,730	NA	NA	3.40	3.39	3.29	5.89	6.62	NA	NA	28.4	31.5	31.6	34.2	34.2	NA	NA
Sep-05	0	NA	0	54	111	NA	NA	5,430	NA	4,230	3,920	3,830	NA	NA	3.58	NA	4.15	5.80	6.24	NA	NA	28.4	NA	31.3	33.2	34.1	NA	NA
Oct-05	0	NA	0	51	107	NA	NA	5,630	NA	4,410	4,220	4,030	NA	NA	5.45	NA	4.99	6.00	6.26	NA	NA	28.3	NA	31.3	33.6	34.0	NA	NA
Nov-05	0	NA	5	48	96	NA	NA	5,550	NA	4,180	4,080	3,940	NA	NA	3.75	NA	5.45	5.76	6.25	NA	NA	28.7	NA	33.0	34.2	34.2	NA	NA
Dec-05	0	NA	22	44	77	NA	NA	5,670	NA	4,190	4,060	3,950	NA	NA	3.38	NA	5.92	5.97	6.43	NA	NA	33.3	NA	35.6	34.1	31.6	NA	NA
Jan-06	0	NA	28	89	128	NA	NA	5,720	NA	4,110	4,330	4,250	NA	NA	5.22	NA	6.30	6.36	6.47	NA	NA	29.4	NA	45.0	35.2	32.2	NA	NA
Feb-06	0	NA	101	117	126	NA	NA	5,670	NA	4,350	4,250	4,040	NA	NA	3.83	NA	6.19	6.14	6.38	NA	NA	27.5	NA	41.3	37.5	49.0	NA	NA
Mar-06	0	NA	190	133	132	NA	NA	5,850	NA	4,290	4,310	4,060	NA	NA	4.14	NA	6.19	6.18	6.18	NA	NA	27.6	NA	43.7	39.9	38.8	NA	NA
Apr-06	0	NA	244	139	119	NA	NA	5,710	NA	4,280	4,310	5,710	NA	NA	5.21	NA	6.24	6.17	6.10	NA	NA	28.9	NA	44.3	41.0	34.0	NA	NA
May-06	0	NA	246	138	112	NA	NA	5,740	NA	4,180	4,290	4,130	NA	NA	4.12	NA	6.16	6.02	6.01	NA	NA	28.3	NA	45.1	42.0	33.9	NA	NA
Jun-06	0	104	249	138	130	NA	NA	5,680	4,280	4,160	4,450	4,080	NA	NA	4.12	5.86	6.14	6.08	6.02	NA	NA	29.0	44.3	45.8	42.0	32.8	NA	NA
Jul-06	0	134	230	217	138	NA	NA	5,140	4,020	3,750	4,060	3,810	NA	NA	5.06	5.90	6.13	6.14	6.06	NA	NA	29.4	40.7	45.0	50.5	37.0	NA	NA
Aug-06	0	160	232	227	137	NA	NA	5,340	4,050	3,860	4,140	3,850	NA	NA	3.89	6.04	6.17	6.34	6.24	NA	NA	27.6	43.1	47.2	50.0	37.8	NA	NA
Sep-06	0	137	235	278	155	NA	NA	5,350	3,960	3,740	3,980	3,870	NA	NA	3.41	6.00	6.16	6.45	6.49	NA	NA	27.8	38.7	27.8	50.5	41.2	NA	NA
Oct-06	0	141	279	323	133	NA	NA	5,230	4,040	3,810	4,000	4,000	NA	NA	5.11	6.02	6.24	6.42	6.21	NA	NA	29.9	39.0	47.3	51.4	35.0	NA	NA
Nov-06	0	159	229	304	155	NA	NA	5,390	4,180	3,840	4,020	4,020	NA	NA	3.64	6.01	6.96	6.46	6.59	NA	NA	27.8	38.7	46.2	53.1	44.0	NA	NA
Dec-06	0	151	233	328	183	NA	NA	5,680	4,290	4,090	4,230	4,360	NA	NA	3.42	6.18	7.05	6.67	6.44	NA	NA	28.6	38.8	47.1	54.0	48.3	NA	NA
Jan-07	0	149	243	335	196	NA	NA	5,310	4,170	3,920	4,010	4,220	NA	NA	5.23	6.13	6.70	6.56	6.36	NA	NA	29.0	37.0	48.0	53.0	49.0	NA	NA
Feb-07	0	144	205	272	178	NA	NA	5,340	4,150	3,800	3,900	4,160	NA	NA	4.16	6.50	6.64	6.62	6.43	NA	NA	28.0	37.0	49.0	53.0	51.0	NA	NA
Mar-07	0	NA	258	310	210	NA	NA	5,500	NA	3,970	4,120	4,200	NA	NA	3.84	NA	6.99	6.92	6.56	NA	NA	29.0	NA	50.0	53.0	50.0	NA	NA
Apr-07	0	161	302	345	217	NA	NA	5,210	3,990	3,830	3,950	4,060	NA	NA	5.25	6.01	6.33	6.44	6.18	NA	NA	28.0	38.0	46.0	44.0	52.0	NA	NA
May-07	0	173	288	317	223	NA	NA	5,260	3,980	3,750	3,850	3,860	NA	NA	3.91	6.05	6.48	6.52	6.61	NA	NA	28.0	36.0	48.0	52.0	54.0	NA	NA
Jun-07	0	169	310	311	191	NA	NA	4,200	3,230	3,020	2,980	3,030	NA	NA	3.38	6.03	6.86	6.85	6.44	NA	NA	28.0	35.0	50.0	51.0	52.0	NA	NA
Jul-07	0	156	293	322	199	NA	NA	4,750	3,400	3,530	3,410	3,520	NA	NA	5.10	6.16	6.37	6.51	6.40	NA	NA	29.0	36.0	51.0	49.0	54.0	NA	NA
Aug-07	0	171	293	306	150	NA	NA	4,860	3,770	3,550	3,570	3,650	NA	NA	3.92	5.91	6.45	6.41	6.06	NA	NA	28.0	36.0	53.0	52.0	55.0	NA	NA
Sep-07	0	184	307	304	135	NA	NA	4,940	3,610	3,570	3,660	3,720	NA	NA	3.58	6.09	6.60	6.46	6.77	NA	NA	29.0	35.0	54.0	53.0	57.0	NA	NA
Oct-07	20	161	329	307	185	NA	NA	4,630	3,300	3,170	3,200	3,350	NA	NA	3.29	6.39	6.51	6.64	6.20	NA	NA	29.0	36.0	55.0	52.0	50.0	NA	NA
Nov-07	0	159	295	258	109	NA	NA	4,400	3,530	3,170	3,160	3,350	NA	NA	3.69	5.88	6.94	6.52	6.20	NA	NA	29	36	53	50	53	NA	NA
Dec-07	0	148	316	290	55	NA	NA	5,440	3,990	3,890	3,980	4,110	NA	NA	3.49	6.04	6.80	6.65	6.05	NA	NA	29	34	51	51	53	NA	NA
Jan-08	NA	NA	289	294	107	302	350	NA	NA	4,190	4,220	4,470	3,720	3,870	NA	NA	6.41	6.37	5.88	6.69	6.27	NA	NA	54	54	50	37	43
Feb-08	NA	NA	189	299	13	313	NA	NA	NA	3,900	4,050	4,280	3,710	NA	NA	NA	6.80	7.00	5.34	6.64	NA	NA	NA	57	49	53	36	NA
Mar-08	NA	143	139	323	0	312	602	NA	4,220	3,900	4,060	4,370	3,630	3,870	NA	6.20	6.45	6.82	5.16	6.92	6.30	NA	32	57	50	57	35	50
Apr-08	NA	116	156	362	96	306	NA	NA	3,800	3,590	3,680	3,840	3,260	NA	NA	5.86	6.18	6.58	5.83	6.51	NA	NA	32	58	50	49	36	NA
May-08	NA	NA	169	337	29	312	406	NA	NA	3,900	4,040	3,950	3,690	3,980	NA	NA	6.21	6.50	5.97	6.29	6.47	NA	NA	58	53	51	36	37
Jun-08	NA	0	293	287	133	302	453	NA	4,570	3,890	3,990	3,940	3,640	3,880	NA	3.84	6.40	6.53	6.12	6.26	6.15	NA	35	54	54	48	35	37

TABLE 11

Zone 3 Field Parameter Measurements of Tracking Wells Through October 2018

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

	Bicarbonate (mg/L)							Conductivity (umhos/cm)							pH (s.u.)							Chloride (mg/L)						
Date	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A
Jul-08	NA	0	268	302	162	313	228	NA	4,140	3,740	3,770	3,850	3,450	3,730	NA	5.94	6.39	7.28	6.33	6.54	6.38	NA	36	49	53	50	33	41
Aug-08	NA	99	201	289	208	316	349	NA	4,230	3,800	3,840	3,790	3,620	3,810	NA	5.83	6.42	6.88	6.46	6.50	6.35	NA	35	52	51	48	34	40
Sep-08	NA	106	211	290	244	310	327	NA	4,170	3,650	3,720	3,340	3,510	3,740	NA	5.86	6.89	7.18	7.09	6.39	6.32	NA	37	42	48	46	35	38
Oct-08	NA	98	84	301	294	321	337	NA	4,080	4,000	3,770	3,820	3,560	3,760	NA	5.74	5.85	6.69	6.31	6.54	6.37	NA	30	50	55	48	38	38
Nov-08	NA	80	50	127	246	335	338	NA	4,120	3,570	3,900	3,730	3,560	3,750	NA	5.55	5.87	6.16	6.41	6.43	6.24	NA	32	53	57	46	34	35
Dec-08	NA	85	39	79	268	351	346	NA	3,990	3,500	4,040	3,660	3,530	3,700	NA	6.05	5.68	5.76	6.86	6.48	6.26	NA	34	52	57	44	36	38
Jan-09	NA	63	10	15	295	351	344	4950	4,190	3,690	4,100	3,860	3,580	3,800	5.5	5.41	4.02	5.41	6.24	6.55	6.25	NA	30	50	57	43	40	39
Apr-09	NA	55	0	174	271	338	385	5110	4,010	4,960	3,900	3,560	3,600	3,710	5.59	5.31	2.88	6.21	6.80	6.43	6.36	NA	29	42	53	40	38	38
Feb-09	NA	74	0	16	268	344	361	NA	4,200	4,220	3,910	3,420	3,580	3,730	NA	5.64	3.03	5.00	6.55	6.43	6.35	NA	29	51	58	43	39	40
Mar-09	NA	89	12	0	306	343	351	NA	4,170	3,430	3,850	3,750	3,580	3,750	NA	5.74	4.56	4.87	7.29	6.44	6.30	NA	31	39	58	40	38	37
May-09	NA	83	0	205	258	337	332	NA	4,250	4,980	3,800	3,600	3,530	3,820	NA	5.80	2.51	6.35	6.99	6.41	6.31	NA	28	51	50	44	36	36
Jun-09	NA	83	0	287	235	334	318	NA	4,010	4,410	3,520	3,400	3,410	3,660	NA	5.60	2.52	7.32	6.98	6.43	6.30	NA	29	51	48	44	39	37
Jul-09	NA	77	0	244	227	328	308	4670	4,030	4,540	3,680	3,370	3,470	3,660	3.56	5.70	2.50	6.45	7.16	7.91	6.30	NA	29	>40	48	50	40	38
Aug-09	NA	50	0	226	85	312	293	NA	4,440	5,200	3,760	3,640	3,490	3,860	NA	5.33	2.51	6.62	6.64	6.58	6.21	NA	29	40	48	51	41	37
Sep-09	NA	65	NA	51	59	306	277	NA	4,370	NA	3,570	3,720	3,390	3,910	NA	5.40	NA	9.18	6.60	6.44	6.30	NA	29	NA	49	59	43	37
Oct-09	NA	94	NA	111	178	335	280	4860	3,980	NA	3,530	3,960	3,360	3,470	5.5	5.60	NA	6.26	5.65	6.41	5.80	NA	28	NA	42	48	41	36
Nov-09	NA	96	0	87	198	252	294	NA	4,260	2,230	3,500	3,970	3,260	3,760	NA	5.80	3.83	7.04	6.10	6.65	6.40	NA	28	7	42	46	127	37
Dec-09	NA	76	0	47	44	280	283	NA	4,350	4,640	3,490	3,950	3,350	3,720	NA	6.10	2.90	7.14	6.93	7.15	6.38	NA	29	41	40	48	97	37
Jan-10	NA	87	0	38	80	302	299	5020	4,460	4,300	3,600	4,150	3,460	3,850	4.56	5.50	2.76	5.45	6.31	6.39	6.06	NA	29	35	40	46	79	37
Feb-10	NA	89	0	22	55	306	272	NA	4,400	4,610	3,440	3,990	3,450	3,810	NA	5.90	3.00	6.26	6.39	6.50	6.27	NA	29	30	36	47	74	37
Mar-10	NA	94	0	28	69	321	282	NA	4,340	4,690	3,440	4,130	3,520	3,800	NA	5.80	2.93	6.62	5.38	6.48	6.42	NA	29	31	37	43	56	37
Apr-10	NA	71	0	234	0	330	265	NA	4,680	4,410	3,490	4,000	3,500	4,080	NA	5.42	2.95	6.38	5.40	6.67	6.10	NA	29	33	34	43	50	38
May-10	NA	72	0	194	0	340	268	NA	4,730	5,030	3,800	4,220	3,860	4,050	NA	5.76	2.67	7.48	3.25	6.14	6.34	NA	29	33	33	43	45	38
Jun-10	NA	66	0	182	0	338	251	NA	4,430	4,930	3,400	4,300	3,460	3,740	NA	5.60	2.74	7.67	2.95	6.66	6.40	NA	29	30	33	43	44	36
Jul-10	NA	81	0	262	0	354	248	5460	4,480	4,670	3,290	3,930	3,260	3,790	3.13	5.78	2.62	7.13	4.46	6.45	6.34	NA	29	30	33	41	44	38
Aug-10	NA	39	0	222	0	358	250	NA	4,330	5,020	3,440	4,340	3,450	3,770	NA	5.25	2.69	7.54	3.01	6.61	6.30	NA	29	32	31	40	42	36
Sep-10	NA	85	0	239	0	332	241	NA	4,450	5,020	3,410	4,250	3,500	3,750	NA	5.76	2.71	7.25	3.01	6.61	6.24	NA	28	32	29	40	45	36
Oct-10	NA	78	0	232	4	354	243	4610	4,710	4,260	3,340	4,090	3,300	3,910	3.88	5.29	2.89	7.12	2.97	6.59	5.99	NA	28	32	29	37	45	36
Nov-10	NA	60	0	210	0	355	224	NA	4,680	4,980	3,610	3,860	3,690	3,790	NA	5.71	2.90	6.67	4.51	6.42	6.41	NA	28	30	27	37	43	38
Dec-10	NA	56	NA	235	20	365	227	NA	4,720	NA	3,610	3,800	3,530	4,020	NA	5.66	NA	7.32	4.70	6.78	6.14	NA	28	NA	29	37	48	34
Jan-11	NA	55	NA	239	103	407	260	NA	5,030	NA	3,540	4,170	3,450	3,990	NA	5.70	NA	7.70	7.04	7.40	7.36	NA	28	NA	31	37	50	38
Feb-11	NA	57	NA	234	16	390	246	NA	4,600	NA	3,510	3,750	3,530	3,850	NA	5.66	NA	7.35	4.94	6.91	6.30	NA	28	NA	26	36	45	35
Mar-11	NA	35	0	237	0	397	245	NA	4,680	5,220	3,430	3,790	3,520	3,860	NA	5.40	2.71	7.43	4.07	6.75	6.36	NA	28	28	27	36	48	36
Apr-11	NA	78	0	262	0	402	247	NA	4,720	5,390	3,490	4,060	3,490	3,940	NA	5.87	2.80	6.96	5.71	6.68	6.35	NA	30	28	29	36	50	37
May-11	NA	76	0	223	0	401	239	NA	4,110	5,390	3,470	3,830	3,550	3,920	NA	5.76	2.65	7.42	3.91	6.81	6.65	NA	30	NA	30	36	51	39
Jun-11	NA	67	0	223	0	412	241	NA	4,710	5,340	3,450	3,820	3,510	3,910	NA	5.52	2.59	7.61	3.74	6.87	6.36	NA	30	30	29	34	51	37
Jul-11	NA	65	0	272	0	405	248	NA	4,650	5,640	3,240	4,040	3,450	3,840	NA	5.48	2.70	7.28	5.47	6.51	7.12	NA	30	33	29	35	50	38
Aug-11	NA	294	0	235	0	405	243	NA	3,770	5,640	3,610	4,440	3,700	3,880	NA	6.42	2.70	7.74	3.17	6.78	6.43	NA	38	33	28	34	49	38
Sep-11	NA	85	0	267	0	400	243	NA	4,600	5,610	3,440	4,380	3,530	3,830	NA	5.87	2.51	6.52	2.83	6.58	6.41	NA	30	33	28	37	50	38
Oct-11	NA	79	0	251	0	414	244	NA	4,580	5,540	3,380	4,200	3,490	3,830	NA	5.73	2.56	7.35	2.88	6.80	6.40	NA	30	32	28	36	51	37
Nov-11	NA	88	0	236	0	406	245	NA	4790	5700	3530	4590	3600	3980	NA	5.9	2.49	6.68	2.86	6.75	6.46	NA	29	32	29	32	51	37
Dec-11	NA	77	0	234	0	408	243	NA	4800	5640	3560	4730	3640	3960	NA	6.06	2.67	6.62	2.99	6.78	6.42	NA	30	32	28	32	52	37
Jan-12	NA	63	NA	217	0	405	224	NA	4790	NA	3650	4680	3540	3940	NA	5.74	NA	6.57	2.91	6.76	6.39	NA	30	NA	29	40	52	37
Feb-12	NA	79	0	213	0	406	234	NA	4720	5580	3570	4800	3640	3980	NA	5.83	2.68	6.83	2.84	6.84	6.3	NA	29	33	28	33	52	37
Mar-12	NA	83	0	230	0	391	224	NA	4690	5300	3600	4830	3660	4010	NA	5.9	2.66	6.63	2.82	6.74	6.39	NA	29	33	28	34	50	37
Apr-12	NA	77	0	221	0	373	223	NA	4680	5420	3560	4810	3520	3990	NA	5.8	2.65	6.38	2.81	6.67	6.28	NA	30	33	28	34	50	36
May-12	NA	90	0	219	0	376	228	NA	4690	5420	3500	5350	3550	3980	NA	5.97	2.46	6.50	2.59	6.6	6.37	NA	30	34	27	35	50	36
Jun-12	NA	69	0	223	0	377	226	NA	4600	5830	3450	5420	3520	3900	NA	5.85	2.73	6.60	2.67	6.68	6.24	NA	29	33	27	32	48	37
Jul-12	NA	77	0	213	0	377	226	NA	4610	5630	3560	5130	3480	3950	NA	5.85	2.68	6.41	3.04	6.54	6.36	NA	30	31	27	31	47	35
Aug-12	NA	86	0	207	0	363	221	NA	4530	5580	3640	5550	3540	3890	NA	5.85	2.58	6.56	2.55	6.63	6.32	NA	30	31	27	31	47	35
Sep-12	NA	66	0	184	0	385	222	NA	4460	5660	3600	5150	3490	3870	NA	5.83	2.52	6.58	2.48	6.62	6.46	NA	30	32	27	31	49	36
Oct-12	NA	63	0	219	0	386	224	NA	4500	6080	3630	5110	3230	3930	NA	5.90	2.55	6.38	2.73	6.75	6.46	NA	30	33	27	31	49	35
Nov-12	NA	87	0	189	0	399	220	NA	4470	6320	3710	5600	3460	3910	NA	6.00	2.64	6.95	2.65	6.75	6.41	NA	30	32	28	30	49	37
Dec-12	NA	82	0	190	0	391	212	NA	4450	6390	3630	5500	3480	3900	NA	5.89	2.50	7.10	2.59	6.75	6.36	NA	29	31	27	31	50	35
Jan-13	NA	73	0	182	0	386	215	NA	4720	7120	4240	5850	3850	4130	NA	5.84	2.48	6.47	2.65	6.84	6.44	NA	30	31	27	32	50	35
Feb-13	NA	80	0	96	0	397	226	NA	4780	6400	3850	5730	3630	4160	NA	5.85	2.43	6.88	2.56	6.64	6.36	NA	29	32	27	33	49	36
Mar-13	NA	76	0	45	NA	379	212	NA	3580	6200	3950	NA	3580	4180	NA	5.70	2.53	6.14	NA	6.69	6.40	NA	29	32	27	NA	50	36
Apr-13	NA	62	0	0	NA	379	210	NA	4540	5950	4440	NA	3540	4010	NA	5.84	2.53	3.72	NA	6.62	6.38	NA	30	32	27	NA	50	36
May-13	NA	54	0	0	NA	384	183	NA	4510	6220	4140	NA	3410	4000	NA	5.72	2.64	3.42	NA	6.82	6.29	NA	30	33	28	NA	51	36
Jun-13	NA	54	0	0	NA	379	185	NA	4580	6040	4310	NA	3420	4120	NA	5.48	2.49	3.00	NA	6.54	6.12	NA	30	33	28	NA	50	34
Jul-13	NA	58	0	0	NA	376	184	NA	4430	5870	4380	NA	3470	4020	NA	5.71	2.54	2.97	NA	6.65	6.29	NA	31	33	27	NA	50	33
Aug-13	NA	35	0	0	NA	365	184	NA	4290	5630	4260	NA	3340	3980	NA	6.08	2.46	2.88	NA	7.03	6.42	NA	31	34	28	NA	50	34
Sep-13	NA	NA	0	0	NA	379	191	NA	NA	5780	4800	NA	3540	3930	NA	NA	2.47	2.65	NA	6.59	6.58	NA	NA	34	32	NA	50	34
Oct-13	NA	NA	0	0	NA	391	199	NA	NA	5540	5230	NA	3620	3950	NA	NA	2.85	2.82	NA	7.26	6.53	NA	NA	34	32	NA	50	34
Nov-13	NA	NA	0	0	NA	385	191	NA	NA	5240	4910	NA	3340	4090	NA	NA	3.07	2.80	NA	6.89	6.35	NA	NA	34	28	NA	49	33
Dec-13	NA	NA	0	0	NA	384	183	NA	NA	5080	4710	NA	3330	4070	NA	NA	2.80	2.77	NA	7.38	6.29	NA	NA	34	28	NA	49	34
Jan-14	NA	NA	0	0	NA	383	198	NA	NA	5450	5100	NA	3430	3870	NA	NA	2.80	2.83	NA	6.73	6.36	NA	NA	32	28	NA	49	34
Feb-14	NA	NA	0	0	NA	367	166	NA	NA	5260	5330	NA	3410	4070	NA	NA	2.76	2.70	NA	6.92	6.40	NA	NA	32	29	NA	54	34
Mar-14	NA	NA	0	0	NA	384	182	NA	NA	5060	5000	NA	3410	3950	NA	NA	2.89	2.69	NA	6.98	6.24	NA	NA	32	29	NA	47	33

TABLE 11

Zone 3 Field Parameter Measurements of Tracking Wells Through October 2018

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

	Bicarbonate (mg/L)							Conductivity (umhos/cm)							pH (s.u.)							Chloride (mg/L)						
Date	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A	504 B	PB-2	PB-4	PB-3	NBL-1	NBL-2	RW-A
Apr-14	NA	NA	0	0	NA	376	179	NA	NA	4680	4960	NA	3200	3990	NA	NA	2.98	2.83	NA	6.75	6.10	NA	NA	32	31	NA	47	33
May-14	NA	NA	0	0	NA	371	114	NA	NA	4620	4740	NA	3240	4040	NA	NA	2.89	2.81	NA	6.68	6.30	NA	NA	32	35	NA	45	32
Jun-14	NA	NA	0	11	NA	369	170	NA	NA	4600	3930	NA	3170	3910	NA	NA	2.98	5.79	NA	6.67	6.40	NA	NA	32	30	NA	44	33
Jul-14	NA	NA	0	0	NA	364	157	NA	NA	4670	4430	NA	3400	4210	NA	NA	2.95	3.61	NA	6.73	6.14	NA	NA	34	28	NA	45	34
Aug-14	NA	NA	0	0	NA	366	168	NA	NA	5000	4550	NA	3390	4240	NA	NA	2.94	3.32	NA	6.64	6.18	NA	NA	32	27	NA	45	34
Sep-14	NA	NA	0	0	NA	356	166	NA	NA	4940	4340	NA	3350	4120	NA	NA	2.97	3.55	NA	6.60	6.19	NA	NA	33	27	NA	45	32
Oct-14	NA	NA	0	0	NA	357	162	NA	NA	4870	4040	NA	3300	3650	NA	NA	2.98	3.96	NA	6.62	6.09	NA	NA	33	27	NA	42	33
Nov-14	NA	NA	0	11	NA	335	153	NA	NA	4670	3760	NA	3360	4230	NA	NA	2.97	4.66	NA	6.73	6.40	NA	NA	34	25	NA	43	32
Dec-14	NA	NA	0	9	NA	336	123	NA	NA	4850	3520	NA	3440	4110	NA	NA	3.01	5.00	NA	6.56	6.26	NA	NA	34	24	NA	40	31
Jan-15	NA	NA	0	12	NA	326	151	NA	NA	4960	3900	NA	3420	4160	NA	NA	2.87	5.75	NA	6.67	6.36	NA	NA	31	26	NA	40	31
Feb-15	NA	NA	0	11	NA	329	141	NA	NA	4670	3110	NA	3280	4170	NA	NA	2.88	6.14	NA	6.26	6.32	NA	NA	33	22	NA	40	34
Mar-15	NA	NA	0	25	NA	323	149	NA	NA	4440	3690	NA	3240	4070	NA	NA	2.98	6.69	NA	6.74	6.09	NA	NA	33	26	NA	40	32
Apr-15	NA	NA	0	33	NA	322	140	NA	NA	4830	4080	NA	3750	4460	NA	NA	2.97	6.18	NA	6.48	6.08	NA	NA	32	25	NA	40	32
May-15	NA	NA	0	67	NA	336	137	NA	NA	4820	3970	NA	3320	4420	NA	NA	3.01	6.85	NA	6.51	6.08	NA	NA	33	26	NA	39	31
Jun-15	NA	NA	0	54	NA	348	136	NA	NA	4890	4180	NA	3320	4470	NA	NA	3.01	6.30	NA	6.43	6.19	NA	NA	30	26	NA	39	32
Jul-15	NA	NA	0	69	NA	349	145	NA	NA	4810	3920	NA	3140	4330	NA	NA	2.91	6.95	NA	6.69	6.03	NA	NA	33	28	NA	38	32
Aug-15	NA	NA	0	57	NA	334	129	NA	NA	4740	4040	NA	3250	4460	NA	NA	3.14	6.86	NA	6.74	6.12	NA	NA	31	29	NA	37	31
Sep-15	NA	NA	0	45	NA	244	112	NA	NA	4770	3910	NA	3170	4450	NA	NA	2.95	6.97	NA	6.62	6.08	NA	NA	30	30	NA	36	31
Oct-15	NA	NA	NA	NA	NA	358	124	NA	NA	NA	NA	NA	3270	4380	NA	NA	NA	NA	NA	6.39	6.40	NA	NA	NA	NA	NA	36	31
Nov-15	NA	NA	NA	NA	NA	351	119	NA	NA	NA	NA	NA	3200	4510	NA	NA	NA	NA	NA	6.74	6.02	NA	NA	NA	NA	NA	36	31
Dec-15	NA	NA	NA	NA	NA	323	106	NA	NA	NA	NA	NA	3170	4490	NA	NA	NA	NA	NA	6.87	6.27	NA	NA	NA	NA	NA	38	31
Jan-16	NA	NA	NA	NA	NA	326	115	NA	NA	NA	NA	NA	3320	4470	NA	NA	NA	NA	NA	6.61	6.29	NA	NA	NA	NA	NA	38	31
Feb-16	NA	NA	NA	NA	NA	316	105	NA	NA	NA	NA	NA	3400	4590	NA	NA	NA	NA	NA	6.81	6.01	NA	NA	NA	NA	NA	38	31
Mar-16	NA	NA	NA	NA	NA	342	106	NA	NA	NA	NA	NA	3390	4740	NA	NA	NA	NA	NA	6.96	6.15	NA	NA	NA	NA	NA	38	31
Apr-16	NA	NA	NA	NA	NA	345	110	NA	NA	NA	NA	NA	3180	4670	NA	NA	NA	NA	NA	6.88	6.06	NA	NA	NA	NA	NA	38	31
May-16	NA	NA	NA	NA	NA	349	107	NA	NA	NA	NA	NA	3180	4770	NA	NA	NA	NA	NA	6.68	6.10	NA	NA	NA	NA	NA	38	31
Jun-16	NA	NA	NA	NA	NA	322	101	NA	NA	NA	NA	NA	3310	4840	NA	NA	NA	NA	NA	7.34	6.05	NA	NA	NA	NA	NA	36	29
Jul-16	NA	NA	NA	NA	NA	319	101	NA	NA	NA	NA	NA	3350	4820	NA	NA	NA	NA	NA	6.90	6.10	NA	NA	NA	NA	NA	37	28
Aug-16	NA	NA	NA	NA	NA	322	101	NA	NA	NA	NA	NA	3270	4600	NA	NA	NA	NA	NA	6.99	6.05	NA	NA	NA	NA	NA	35	29
Sep-16	NA	NA	NA	NA	NA	324	99	NA	NA	NA	NA	NA	3340	4690	NA	NA	NA	NA	NA	6.94	6.00	NA	NA	NA	NA	NA	38	29
Oct-16	NA	NA	NA	NA	NA	317	77	NA	NA	NA	NA	NA	3230	4590	NA	NA	NA	NA	NA	6.57	6.05	NA	NA	NA	NA	NA	39	29
Nov-16	NA	NA	NA	NA	NA	315	84	NA	NA	NA	NA	NA	3300	4850	NA	NA	NA	NA	NA	6.84	6.09	NA	NA	NA	NA	NA	39	31
Dec-16	NA	NA	NA	NA	NA	299	76	NA	NA	NA	NA	NA	3230	4840	NA	NA	NA	NA	NA	6.61	6.00	NA	NA	NA	NA	NA	40	31
Jan-17	NA	NA	NA	NA	NA	329	80	NA	NA	NA	NA	NA	3460	4,810	NA	NA	NA	NA	NA	6.66	5.87	NA	NA	NA	NA	NA	40	30
Feb-17	NA	NA	NA	NA	NA	311	85	NA	NA	NA	NA	NA	3350	4830	NA	NA	NA	NA	NA	6.63	6.03	NA	NA	NA	NA	NA	40	29
Mar-17	NA	NA	NA	NA	NA	NS	82	NA	NA	NA	NA	NA	NS	4900	NA	NA	NA	NA	NA	NS	5.89	NA	NA	NA	NA	NA	NS	29
Apr-17	NA	NA	NA	NA	NA	324	80	NA	NA	NA	NA	NA	3340	5000	NA	NA	NA	NA	NA	6.37	5.45	NA	NA	NA	NA	NA	41	30
May-17	NA	NA	NA	NA	NA	296	75	NA	NA	NA	NA	NA	3540	5030	NA	NA	NA	NA	NA	6.58	5.81	NA	NA	NA	NA	NA	46	29
Jun-17	NA	NA	NA	NA	NA	300	55	NA	NA	NA	NA	NA	3540	4980	NA	NA	NA	NA	NA	6.57	5.78	NA	NA	NA	NA	NA	41	29
Jul-17	NA	NA	NA	NA	NA	276	42	NA	NA	NA	NA	NA	3410	4930	NA	NA	NA	NA	NA	6.55	5.42	NA	NA	NA	NA	NA	41	29
Aug-17	NA	NA	NA	NA	NA	324	53	NA	NA	NA	NA	NA	3480	4950	NA	NA	NA	NA	NA	7.47	5.76	NA	NA	NA	NA	NA	41	29
Sep-17	NA	NA	NA	NA	NA	311	61	NA	NA	NA	NA	NA	3100	4950	NA	NA	NA	NA	NA	6.63	5.79	NA	NA	NA	NA	NA	42	29
Oct-17	NA	NA	NA	NA	NA	305	57	NA	NA	NA	NA	NA	3370	5120	NA	NA	NA	NA	NA	6.44	5.68	NA	NA	NA	NA	NA	43	30
Nov-17	NA	NA	NA	NA	NA	297	48	NA	NA	NA	NA	NA	3320	5020	NA	NA	NA	NA	NA	6.58	5.79	NA	NA	NA	NA	NA	42	30
Dec-17	NA	NA	NA	NA	NA	297	49	NA	NA	NA	NA	NA	3430	5060	NA	NA	NA	NA	NA	6.83	5.87	NA	NA	NA	NA	NA	41	30
Jan-18	NA	NA	NA	NA	NA	282	56	NA	NA	NA	NA	NA	3420	5100	NA	NA	NA	NA	NA	6.68	5.58	NA	NA	NA	NA	NA	40	30
Feb-18	NA	NA	NA	NA	NA	336	NA	NA	NA	NA	NA	NA	3420	NA	NA	NA	NA	NA	NA	6.76	NA	NA	NA	NA	NA	NA	40	NA
Mar-18	NA	NA	NA	NA	NA	295	54	NA	NA	NA	NA	NA	3300	5050	NA	NA	NA	NA	NA	6.86	5.85	NA	NA	NA	NA	NA	40	30
Apr-18	NA	NA	NA	NA	NA	307	46	NA	NA	NA	NA	NA	3230	4910	NA	NA	NA	NA	NA	6.60	5.69	NA	NA	NA	NA	NA	41	30
May-18	NA	NA	NA	NA	NA	311	57	NA	NA	NA	NA	NA	3430	5060	NA	NA	NA	NA	NA	6.57	5.77	NA	NA	NA	NA	NA	41	30
Jun-18	NA	NA	NA	NA	NA	307	43	NA	NA	NA	NA	NA	3160	4980	NA	NA	NA	NA	NA	7.09	5.80	NA	NA	NA	NA	NA	41	29
Jul-18	NA	NA	NA	NA	NA	299	30	NA	NA	NA	NA	NA	3300	4800	NA	NA	NA	NA	NA	7.02	5.46	NA	NA	NA	NA	NA	42	29
Aug-18	NA	NA	NA	NA	NA	280	45	NA	NA	NA	NA	NA	3280	5060	NA	NA	NA	NA	NA	7.44	5.70	NA	NA	NA	NA	NA	39	28
Sep-18	NA	NA	NA	NA	NA	307	42	NA	NA	NA	NA	NA	3170	5030	NA	NA	NA	NA	NA	7.12	5.80	NA	NA	NA	NA	NA	39	28
Oct-18	NA	NA	NA	NA	NA	299	42	NA	NA	NA	NA	NA	3470	5230	NA	NA	NA	NA	NA	6.59	5.47	NA	NA	NA	NA	NA	40	28

Notes:

Parameter monitoring of wells NBL-2 and RW-A started in January 2008.

NA indicates that data are not available because a sample was not or could not be collected

NBL-1 "insufficient water volume" for sampling starting in March 2013 due to obstruction (mud).

Well 0504 B and PB-series wells are dry or have insufficient volume to collect sample as shown

No sample 3/23/17 in NBL-2 due to pump failure

No sample 2/27/18 in RW-A due to pump failure

TABLE 12

Zone 3 Field Parameter Measurements of NW and MW-Series Wells Through October 2018

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

	Bicarbonate (mg/L)							Conductivity (umhos/cm)							pH (s.u.)							Chloride (mg/L)						
Date	NW-1	NW-2	NW-3	NW-4	NW-5	MW-6	MW-7	NW-1	NW-2	NW-3	NW-4	NW-5	MW-6	MW-7	NW-1	NW-2	NW-3	NW-4	NW-5	MW-6	MW-7	NW-1	NW-2	NW-3	NW-4	NW-5	MW-6	MW-7
Jun-09	137	351	484	196	502	NA	NA	4,170	3,640	3,350	4,270	3,450	NA	NA	5.93	6.27	6.52	6.15	6.52	NA	NA	26	39	40	31	45	NA	NA
Jul-09	127	333	483	212	577	NA	NA	4,270	3,660	3,380	4,400	3,440	NA	NA	6.25	6.15	6.40	6.64	6.30	NA	NA	27	39	37	32	45	NA	NA
Aug-09	106	319	458	220	563	NA	NA	4,460	3,820	3,530	4,460	3,670	NA	NA	5.91	6.16	6.40	6.30	6.51	NA	NA	26	37	36	33	46	NA	NA
Sep-09	112	328	457	232	511	NA	NA	4,420	3,850	3,570	4,530	3,650	NA	NA	6.00	6.35	6.51	6.55	6.88	NA	NA	26	37	37	32	46	NA	NA
Oct-09	146	341	490	243	597	NA	NA	4,060	3,480	3,250	4,080	3,340	NA	NA	7.01	6.73	6.91	6.59	7.15	NA	NA	25	36	36	29	48	NA	NA
Nov-09	117	380	475	154	604	NA	NA	4,330	3,670	3,390	4,270	3,560	NA	NA	6.50	6.34	6.70	5.96	6.70	NA	NA	27	39	38	30	52	NA	NA
Dec-09	124	402	502	167	612	NA	NA	4,320	3,560	3,520	4,260	3,600	NA	NA	6.11	6.38	6.52	6.13	6.89	NA	NA	26	41	39	30	52	NA	NA
Jan-10	123	432	524	167	591	NA	NA	4,310	3,820	3,680	4,230	3,680	NA	NA	6.68	6.26	6.33	6.10	6.35	NA	NA	26	43	41	29	53	NA	NA
Feb-10	119	428	554	173	590	NA	NA	4,280	3,620	3,630	4,150	3,400	NA	NA	6.57	6.47	6.55	6.28	6.76	NA	NA	26	45	45	29	53	NA	NA
Mar-10	127	415	546	192	595	NA	NA	4,260	3,540	3,650	4,080	3,640	NA	NA	6.90	6.52	6.88	6.36	6.97	NA	NA	26	43	46	29	54	NA	NA
Apr-10	123	404	569	173	589	NA	NA	4,560	3,930	3,950	4,260	3,960	NA	NA	5.72	5.96	6.22	5.76	6.32	NA	NA	26	42	47	30	50	NA	NA
May-10	128	400	573	174	597	NA	NA	4,520	3,890	4,210	4,440	3,830	NA	NA	6.16	6.33	6.61	6.09	6.88	NA	NA	26	42	49	29	54	NA	NA
Jun-10	126	395	606	168	584	NA	NA	4,210	3,540	3,720	4,020	3,540	NA	NA	6.11	6.36	6.63	6.09	6.86	NA	NA	26	43	50	30	53	NA	NA
Jul-10	160	389	561	168	590	NA	NA	4,200	3,630	3,690	4,030	3,590	NA	NA	6.12	6.46	6.69	6.17	6.71	NA	NA	26	43	49	30	53	NA	NA
Aug-10	121	402	563	172	501	NA	NA	4,190	3,530	3,680	3,990	3,490	NA	NA	6.13	6.50	6.63	6.11	6.19	NA	NA	26	42	49	30	47	NA	NA
Sep-10	129	401	533	177	597	NA	NA	4,160	3,500	3,680	3,970	3,560	NA	NA	6.10	6.42	6.60	6.05	6.52	NA	NA	25	40	47	28	53	NA	NA
Oct-10	134	399	508	163	585	NA	NA	4,190	3,540	3,690	4,040	3,630	NA	NA	6.17	6.50	6.49	6.12	6.84	NA	NA	25	41	44	28	53	NA	NA
Nov-10	132	390	488	155	567	NA	NA	4,220	3,600	3,680	4,080	3,650	NA	NA	5.94	6.31	6.56	5.92	6.62	NA	NA	24	41	44	28	52	NA	NA
Dec-10	138	390	490	175	563	NA	NA	4,340	3,650	3,860	4,120	3,760	NA	NA	6.30	6.43	6.68	6.05	6.85	NA	NA	24	40	45	27	51	NA	NA
Jan-11	141	395	511	169	610	NA	NA	4,350	3,750	3,860	4,210	3,690	NA	NA	6.49	6.65	6.83	6.20	7.10	NA	NA	25	39	46	27	51	NA	NA
Feb-11	151	391	490	171	622	NA	NA	4,180	3,630	3,750	4,090	3,640	NA	NA	6.37	6.52	6.69	6.19	6.94	NA	NA	25	40	45	28	51	NA	NA
Mar-11	150	409	489	171	627	NA	NA	4,200	3,620	3,770	4,070	3,670	NA	NA	6.70	6.57	6.77	6.26	6.90	NA	NA	25	41	47	28	52	NA	NA
Apr-11	155	395	489	168	557	NA	NA	4,280	3,700	3,820	4,190	3,620	NA	NA	6.36	6.52	6.85	6.20	6.91	NA	NA	25	43	48	30	51	NA	NA
May-11	133	377	465	173	549	NA	NA	4,330	3,730	3,800	4,200	3,650	NA	NA	6.18	6.50	6.81	6.27	6.83	NA	NA	26	43	49	30	50	NA	NA
Jun-11	135	399	468	158	545	NA	NA	4,280	3,700	3,790	4,170	3,640	NA	NA	6.17	6.35	6.75	6.01	6.91	NA	NA	26	43	48	29	49	NA	NA
Jul-11	140	398	445	162	544	NA	NA	4,160	3,670	3,780	4,120	3,600	NA	NA	6.64	6.84	6.50	6.81	6.89	NA	NA	26	42	50	29	50	NA	NA
Aug-11	141	393	435	162	582	234	496	4,130	3,590	3,530	4,050	3,520	4,100	3,850	6.58	6.56	6.80	6.21	7.05	6.91	6.73	26	42	48	29	50	34	50
Sep-11	145	367	437	139	583	215	486	4,120	3,630	3,630	3,950	3,480	3,880	3,580	6.59	6.65	6.94	6.14	7.10	6.22	6.58	28	43	46	30	50	31	49
Oct-11	266	368	399	163	591	189	490	3,880	3,630	3,620	4,090	3,540	3,910	3,510	6.60	6.53	6.98	6.30	7.00	6.71	6.77	35	42	46	28	52	31	50
Nov-11	157	379	417	170	583	240	506	4,260	3,750	3,800	4,330	3,620	3,930	3,680	6.49	6.65	6.95	6.49	7.00	6.45	6.98	25	43	46	29	52	34	49
Dec-11	155	362	423	163	569	234	468	4,410	3,840	3,830	4,320	3,720	3,910	3,710	6.74	6.79	6.75	6.41	7.18	6.62	6.83	26	42	44	29	53	34	51
Jan-12	123	347	401	151	491	224	451	4,300	3,760	3,760	4,380	3,370	4,040	3,850	6.61	6.55	6.77	6.28	6.94	6.59	6.75	26	42	42	29	48	38	50
Feb-12	212	368	406	158	490	227	432	4,280	3,790	3,760	4,350	3,400	3,880	3,730	6.75	6.52	6.67	6.12	6.97	6.54	6.68	25	42	43	29	45	37	46
Mar-12	161	344	385	157	492	238	410	4,210	3,780	3,750	4,380	3,700	3,880	3,690	7.01	6.51	6.75	6.23	6.99	6.47	6.70	24	40	42	28	47	39	46
Apr-12	132	327	385	149	484	215	351	4,240	3,810	3,730	4,370	3,720	3,810	3,660	6.54	6.36	6.54	5.90	6.95	6.41	6.62	26	40	42	29	47	39	46
May-12	182	341	396	126	478	230	375	4,250	3,830	3,750	4,370	3,750	3,830	3,620	6.70	6.47	6.79	6.05	7.00	6.34	6.54	23	40	39	29	46	39	46
Jun-12	180	251	380	134	446	223	363	4,080	3,750	3,760	4,280	3,780	3,840	3,500	6.67	6.53	6.61	6.00	6.98	6.52	6.65	23	39	39	28	45	43	40
Jul-12	180	245	360	133	417	389	349	4,100	3,690	3,560	4,340	3,740	3,670	3,420	6.61	6.50	6.66	6.03	6.91	6.81	6.41	23	39	39	29	45	41	41
Aug-12	178	296	373	135	418	384	332	3,860	3,730	3,650	4,240	3,810	3,690	3,630	7.05	7.27	6.57	6.11	6.91	6.82	6.47	23	38	39	28	44	42	41
Sep-12	225	222	382	118	417	391	328	3,840	3,630	3,550	4,190	3,740	3,980	3,640	7.43	6.97	6.95	6.20	7.10	6.98	6.60	22	40	39	28	45	76	40
Oct-12	225	238	389	116	401	267	339	3,890	3,960	3,610	4,230	3,810	3,810	3,650	7.07	6.35	6.78	6.20	7.02	6.88	6.61	22	39	38	28	44	60	41
Nov-12	216	226	358	101	388	239	355	3,830	3,670	3,570	4,190	3,810	4,030	3,580	7.29	6.43	6.78	6.17	7.02	7.05	6.93	21	40	39	29	43	38	42
Dec-12	NA	297	430	96	384	228	329	NA	3,690	3,560	4,200	3,750	3,920	3,590	NA	6.42	6.77	5.84	6.81	6.89	6.60	NA	40	40	29	42	36	40
Jan-13	257	293	395	106	383	237	319	4,140	4,000	3,790	4,410	3,820	4,500	4,020	7.03	6.67	6.93	6.50	6.91	6.53	6.59	21	40	39	29	39	35	41
Feb-13	303	307	386	103	409	187	376	4,240	4,020	3,760	4,390	4,190	3,860	3,790	7.85	6.51	6.83	6.02	6.89	6.96	6.57	21	38	39	29	40	35	41
Mar-13	301	306	397	106	371	NA	377	4,180	4,030	3,780	4,390	4,090	NA	3,710	7.77	6.47	6.77	6.07	6.80	NA	6.78	20	38	38	28	38	NA	41
Apr-13	301	268	399	107	374	187	364	3,980	3,840	3,600	4,150	4,060	4,260	3,690	7.60	6.52	6.81	6.09	6.77	6.40	6.59	20	38	37	28	40	34	41
May-13	329	269	465	72	345	174	371	3,910	3,850	3,620	4,110	4,020	4,150	3,640	7.70	6.42	6.82	6.38	6.70	7.39	6.88	20	38	36	28	38	32	42
Jun-13	332	276	365	70	343	203	374	4,020	3,990	3,530	4,100	4,200	4,290	3,730	7.44	6.52	6.42	6.47	6.67	6.24	6.59	19	37	36	27	38	30	42
Jul-13	316	283	344	69	339	187	374	3,900	3,880	3,440	4,000	4,100	4,260	3,500	7.46	6.41	6.53	6.96	6.65	6.31	6.72	19	36	36	27	40	32	41
Aug-13	297	288	356	100	345	170	385	3,860	3,950	3,610	3,910	4,110	4,190	3,660	7.10	6.46	6.47	7.04	6.60	7.54	6.61	19	36	36	27	38	32	41
Sep-13	320	280	349	NA	319	174	396	3,820	3,880	3,490	NA	4,030	4,300	3,680	7.60	6.60	6.44	NA	6.76	7.00	6.77	21	36	35	NA	37	31	41
Oct-13	345	279	345	108	324	197	407	3,870	3,890	3,470	3,980	4,040	4,040	3,410	7.58	6.86	6.79	6.83	6.98	6.46	6.61	20	36	35	29	38	31	42
Nov-13	360	273	351	200	335	177	401	3,800	4,030	3,510	3,920	4,060	4,000	3,440	7.03	6.51	6.76	6.61	6.85	7.56	7.11	20	35	35	29	36	30	42
Dec-13	405	260	361	167	313	181	416	3,810	4,040	3,640	3,690	4,080	3,890	3,460	6.96	6.49	6.67	6.61	6.77	7.47	7.06	20	35	35	26	35	30	42
Jan-14	352	226	389	88	NA	184	410	3,580	3,970	3,650	3,670	NA	4,260	3,540	6.89	6.48	6.79	7.00	NA	6.83	6.81	18	35	35	26	NA	29	43
Feb-14	360	227	363	121	315	NA	396	3,860	4,010	3,400	3,720	4,070	NA	3,480	7.39	6.53	6.82	6.85	6.82	NA	7.02	18	35	35	26	36	NA	42
Mar-14	384	229	416	129	339	167	404	3,830	3,990	3,650	3,610	4,120	3,280	3,470	7.18	5.98	6.84	6.61	6.94	6.68	7.06	18	35	34	25	37	30	42
Apr-14	423	227	438	NA	368	191	404	3,760	3,950	3,650	NA	4,130	3,980	3,080	6.80	5.75	6.85	NA	7.01	6.48	6.75	18	35	34	NA	37	30	42
May-14	398	223	435	123	354	162	392	3,730	3,970	3,620	3,720	4,090	3,930	3,360	7.09	6.54	6.81	6.75	6.98	7.62	7.02	19	35	35	25	36	29	42
Jun-14	428	209	437	106	358	NA	379	3,710	3,960	3,640	3,720	4,110	NA	3,280	6.99	6.50	6.83	7.01	6.85	NA	6.82	19	35	35	25	35	NA	42

TABLE 12

Zone 3 Field Parameter Measurements of NW and MW-Series Wells Through October 2018
United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

	Bicarbonate (mg/L)							Conductivity (umhos/cm)							pH (s.u.)							Chloride (mg/L)						
Date	NW-1	NW-2	NW-3	NW-4	NW-5	MW-6	MW-7	NW-1	NW-2	NW-3	NW-4	NW-5	MW-6	MW-7	NW-1	NW-2	NW-3	NW-4	NW-5	MW-6	MW-7	NW-1	NW-2	NW-3	NW-4	NW-5	MW-6	MW-7
Jul-14	416	210	441	105	350	171	341	3,850	4,170	3,810	3,990	4,270	3,610	3,520	7.15	6.33	6.66	6.84	6.76	7.46	6.57	19	35	34	25	35	35	40
Aug-14	446	227	444	107	341	183	362	3,910	4,230	3,830	4,010	4,280	4,210	3,560	7.61	6.32	6.73	6.66	6.94	7.65	6.88	19	35	35	25	35	29	40
Sep-14	455	227	505	100	309	190	373	3,740	4,100	3,840	3,900	4,190	4,010	3,500	7.05	6.31	7.03	6.53	6.85	7.71	7.09	20	35	34	24	35	28	40
Oct-14	460	189	414	108	304	192	362	3,780	4,220	3,850	4,060	4,300	4,330	3,580	6.77	6.40	6.75	6.72	6.74	7.08	6.73	18	35	34	24	34	29	40
Nov-14	476	209	469	148	304	154	340	3,750	4,170	3,890	4,030	4,290	3,210	3,680	6.98	6.49	6.84	7.02	6.88	6.65	7.50	18	35	35	25	34	25	40
Dec-14	458	219	464	125	273	144	358	3,660	4,040	3,800	3,930	4,170	4,030	3,710	7.12	6.49	6.88	6.83	6.96	7.63	7.24	18	35	34	25	33	31	41
Jan-15	455	219	440	140	279	186	378	3,650	4,110	3,810	3,900	4,290	4,300	3,680	7.09	6.48	6.92	7.01	6.69	6.97	6.86	18	35	35	25	33	31	41
Feb-15	494	210	466	141	246	172	361	3,710	4,120	3,870	3,950	4,060	4,160	3,580	7.30	6.35	6.96	6.69	6.75	7.35	7.38	17	35	35	24	33	30	41
Mar-15	499	194	471	141	253	181	357	3,540	4,050	3,740	3,850	4,020	4,180	3,490	7.32	6.28	7.06	6.61	6.73	7.02	7.48	17	32	34	24	32	29	41
Apr-15	477	194	461	156	260	192	352	3,890	4,380	4,110	4,250	4,570	4,330	3,750	6.94	6.27	6.80	6.42	6.44	6.86	6.48	17	32	36	23	34	29	39
May-15	542	NA	473	135	257	193	343	3,800	NA	3,860	4,100	4,420	4,410	3,671	6.95	NA	6.88	6.77	6.60	7.52	7.16	17	NA	33	23	32	30	40
Jun-15	498	197	476	158	223	196	305	3,770	4,370	4,030	4,180	4,430	4,460	3,940	7.08	6.43	7.03	6.93	6.68	6.33	6.84	17	33	35	23	34	31	40
Jul-15	490	197	480	142	231	208	315	3,800	4,360	4,090	4,120	4,490	4,200	3,620	7.19	6.19	6.74	6.57	6.41	7.18	6.90	17	33	35	23	34	31	38
Aug-15	474	185	456	133	212	191	280	3,770	4,380	4,100	4,120	4,480	4,350	3,620	7.22	6.19	6.93	6.81	6.65	7.68	7.83	17	33	35	23	34	30	38
Sep-15	484	181	488	118	235	224	NA	3,690	4,330	4,030	4,040	4,410	4,210	NA	7.20	6.30	7.05	7.02	6.80	7.87	NA	16	32	35	23	33	30	NA
Oct-15	NA	182	477	116	241	NA	NA	NA	4,270	4,010	4,190	4,400	NA	NA	NA	6.34	7.06	6.93	6.71	NA	NA	NA	32	35	22	33	NA	NA
Nov-15	492	199	488	111	204	NA	263	3,700	4,410	4,040	4,070	4,440	NA	3,830	8.00	6.54	7.05	6.83	6.95	NA	7.88	17	33	36	22	33	NA	38
Dec-15	491	173	518	103	243	NA	276	3,680	4,330	4,090	4,040	4,500	NA	3,800	6.67	6.50	6.94	6.91	6.68	NA	7.07	20	33	35	22	33	NA	38
Jan-16	464	155	526	92	246	NA	272	3,650	4,410	4,430	4,120	4,580	NA	3,360	6.53	6.41	7.22	6.59	6.43	NA	6.52	16	34	38	22	34	NA	37
Feb-16	474	153	496	83	247	NA	255	3,650	4,490	4,280	4,010	4,450	NA	3,940	6.85	6.12	7.19	6.61	6.41	NA	7.84	20	34	37	21	34	NA	37
Mar-16	477	167	506	87	135	NA	251	3,770	4,500	4,390	4,080	4,720	NA	4,040	7.03	6.26	7.51	6.86	6.27	NA	7.35	19	33	36	21	32	NA	38
Apr-16	488	161	512	85	133	NA	258	3,770	4,400	4,370	4,070	4,730	NA	3,940	7.46	6.14	7.40	6.67	6.10	NA	6.76	17	33	36	21	32	NA	38
May-16	482	NA	494	85	139	NA	261	3,740	NA	4,390	4,100	4,720	NA	3,940	7.48	NA	7.50	6.62	6.26	NA	6.46	17	NA	36	21	32	NA	38
Jun-16	429	138	497	87	99	NA	242	3,720	4,570	4,470	4,120	4,880	NA	3,890	7.57	6.27	7.47	6.73	6.09	NA	7.84	16	29	34	20	30	NA	35
Jul-16	459	160	437	79	98	NA	239	3,730	4,550	4,400	4,060	4,800	NA	3,860	7.50	6.26	7.40	6.63	6.10	NA	6.50	15	29	35	20	30	NA	34
Aug-16	430	163	239	82	106	NA	223	3,440	4,300	4,010	3,840	4,530	NA	3,840	7.56	6.19	7.14	6.67	6.04	NA	7.92	14	29	33	21	30	NA	34
Sep-16	442	165	427	79	113	NA	227	3,520	4,370	4,170	3,920	4,590	NA	3,820	7.54	6.24	7.26	6.78	6.05	NA	7.99	16	29	32	21	30	NA	34
Oct-16	449	159	434	71	101	NA	229	3,700	4,500	4,300	4,040	4,720	NA	3,850	7.36	6.20	7.24	6.80	6.08	NA	6.39	15	30	32	20	30	NA	34
Nov-16	467	156	445	55	99	NA	213	3,610	4,430	4,160	3,980	4,730	NA	3,900	7.35	6.24	7.42	6.50	6.10	NA	7.92	15	31	33	22	30	NA	35
Dec-16	427	145	429	55	80	NA	201	3,390	4,420	3,910	3,950	4,690	NA	3,830	7.29	6.26	7.37	6.18	5.98	NA	7.32	15	31	33	22	31	NA	35
Jan-17	463	146	441	55	80	NA	240	3,600	4,340	4,110	3,890	4,640	NA	4,060	7.06	6.34	7.40	6.79	6.08	NA	6.54	15	31	33	22	31	NA	35
Feb-17	421	152	440	19	32	NA	231	3,490	4,340	3,900	3,790	4,490	NA	3,770	7.08	6.21	7.42	5.22	5.90	NA	7.66	14	31	34	22	31	NA	35
Mar-17	463	148	463	33	64	NA	208	3,750	4,410	4,120	4,020	4,710	NA	4,090	6.85	6.10	7.28	6.30	5.71	NA	7.66	14	31	34	22	31	NA	34
Apr-17	463	134	407	41	58	NA	224	3,800	4,450	4,130	4,030	4,780	NA	3,970	7.12	6.10	6.97	6.72	5.66	NA	6.39	16	31	35	22	31	NA	34
May-17	420	136	438	38	49	NA	213	3,800	4,480	4,140	4,080	4,870	NA	4,000	7.12	6.12	7.19	6.34	5.69	NA	7.29	15	31	34	21	30	NA	33
Jun-17	413	128	415	30	49	NA	213	3,690	4,350	3,990	3,980	4,790	NA	3,940	7.15	6.04	7.26	6.60	6.05	NA	7.32	15	31	35	21	30	NA	35
Jul-17	445	134	396	39	34	NA	215	3,660	4,460	4,040	4,000	4,900	NA	3,770	7.10	6.03	6.96	6.80	5.40	NA	6.37	15	31	35	21	30	NA	34
Aug-17	408	139	405	36	16	NA	219	3,580	4,380	3,940	3,920	4,750	NA	3,800	7.17	6.04	7.22	6.47	5.54	NA	7.93	15	30	35	22	31	NA	33
Sep-17	390	149	396	40	36	NA	222	3,550	4,360	3,960	3,950	4,730	NA	3,750	7.24	6.14	7.23	6.70	5.70	NA	7.48	16	29	34	22	30	NA	34
Oct-17	396	141	432	43	30	NA	243	3,700	4,470	4,080	4,040	4,860	NA	3,880	7.05	6.14	7.23	6.71	5.48	NA	6.80	16	29	35	23	31	NA	34
Nov-17	389	150	433	51	24	NA	226	3,620	4,390	3,930	3,930	4,760	NA	3,870	7.17	6.09	7.10	6.51	5.33	NA	7.65	16	30	35	22	32	NA	35
Dec-17	390	NA	447	48	18	NA	226	3,540	NA	4,000	3,950	4,820	NA	3,950	6.71	NA	7.40	6.66	5.25	NA	7.69	15	NA	36	22	32	NA	36
Jan-18	378	141	429	37	17	NA	259	3,580	4,440	4,040	3,980	4,840	NA	3,840	6.79	5.89	7.47	6.03	5.14	NA	7.66	16	31	34	23	32	NA	37
Feb-18	359	140	484	30	24	NA	222	3,690	4,380	3,910	3,910	4,650	NA	3,930	7.50	6.14	7.30	5.91	5.55	NA	7.51	16	30	33	22	33	NA	36
Mar-18	364	132	475	32	24	NA	213	3,550	4,360	3,930	3,840	4,660	NA	3,920	6.99	6.11	7.43	6.40	5.57	NA	7.21	14	30	33	21	31	NA	35
Apr-18	356	116	432	26	13	NA	210	3,570	4,300	3,920	3,800	5,390	NA	3,720	6.99	6.02	7.21	6.42	4.52	NA	7.53	15	29	31	21	30	NA	33
May-18	354	116	493	24	14	NA	206	3,620	4,400	3,990	3,850	4,750	NA	3,850	7.28	5.97	7.17	6.22	5.27	NA	7.64	14	29	30	21	30	NA	33
Jun-18	349	110	445	21	18	NA	190	3,600	4,450	3,970	3,830	4,740	NA	3,450	7.13	5.99	7.24	6.24	5.22	NA	7.81	15	29	33	21	30	NA	33
Jul-18	300	98	390	18	12	NA	207	3,510	4,390	3,960	3,830	4,540	NA	3,900	7.22	5.83	7.10	6.20	4.98	NA	7.44	15	30	33	22	30	NA	33
Aug-18	256	85	408	18	9	NA	191	3,500	4,470	3,930	3,920	4,770	NA	3,600	7.29	5.88	6.91	5.81	4.80	NA	6.65	14	29	34	21	30	NA	32
Sep-18	306	97	420	18	40	NA	189	3,500	4,380	3,890	3,870	4,630	NA	3,920	7.28	5.89	7.10	6.24	5.52	NA	6.99	14	29	34	21	29	NA	33
Oct-18	329	100	448	18	55	NA	201	3,720	4,610	4,100	4,040	4,850	NA	4,230	7.23	6.02	6.96	6.31	5.86	NA	6.29	14	30	34	21	29	NA	33

NA indicates that data are not available because a sample was not or could not be collected
No Sample for well NW-2 on 12-20-17 due to pump failure.

TABLE 13

Historical Zone 3 Seepage Migration Evaluation

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

End Point Well	Starting Point	Distance Between Both Points (ft)	Time for Onset		Travel Time (ft/yr)	Basis for Determining Onset Date for Seepage Impacts At Selected Points
			Seepage Impacts at Starting Point (date)	Seepage Impacts at End Point (date)		
420	North Cell	2,100	1980	Oct-02	95	Bicarbonate concentration greater than 500 mg/L
504 B	North Cell	2,450	1980	Jul-92	204	Bicarbonate concentration less than 100 mg/L
EPA 14	North Cell	1,520	1980	Apr-96	95	Bicarbonate concentration greater than 500 mg/L
PB 2	North Cell	3,080	1980	Oct-02	140	Bicarbonate concentrations first declining to 50 mg/L at Well PB 2
PB 2	504 B	630	Jul-92	Oct-02	61	Bicarbonate concentrations first declining to 50 mg/L at each well
PB 4	PB 2	52	Apr-03	Feb-04	60	Bicarbonate concentrations first persistently at or below 50 mg/L at each well
PB 4	PB 2	52	Jan-08	Nov-08	58	Bicarbonate concentrations again declined to below 50 mg/L at each well
PB 3	PB 4	53	Oct-12	Mar-13	128	Bicarbonate concentrations declined to below 50 mg/L at Well PB 3
			Geometric Mean		96	

End Point Well	Starting Point Well	Distance Between Both Points (ft)	Time for Onset		Net Migration Distance (ft)	Basis for Determining Onset Date for Seepage Impacts At Selected Points (analysis circa 2015)
			Seepage Impacts at Starting Point (date)	Seepage Impacts at End Point (date)		
NBL 1	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Since Dec-05, water quality in the northern tracking wells (including NBL 1) has varied significantly (for example, see the field bicarbonate measurements in Table 11 and the lab bicarbonate measurements shown in Figure 40). This reflects the influence of pumping systems (which have changed over time) and variable mixing of impacted water with background water drawn in from the west. Full seepage impact has occurred at PB 4 since Nov-08 (bicarbonate < 50 mg/L) or Jan-09 (pH < 5.0). To the north of this well, NBL 1 has historically shown strongly degraded water quality in terms of both bicarbonate and pH (Table 11) as well as other constituents (see laboratory analytical data for Jan-13 [subsequent sampling was suspended due to water level decline] in Appendix B; e.g., elevated aluminum, cobalt, and nickel). Based on these data, the leading edge of the impacted water is shown as passing through NBL 1 in Figure 35. Between impacted wells PB 4 and NBL 1, the water quality at PB 3 significantly improved during 2010 and 2011 and was stable until Oct-12 when seepage impact began (Table 11 and Appendix B), indicating the high degree of geochemical variability, sometimes at very close spacing, in the northern part of Zone 3. Note that full seepage impact occurred at PB 3 since Mar-13 (bicarbonate < 50 mg/L) or Apr-13 (pH < 5.0). Water quality improved significantly at PB 3 since Nov-2014, but the most recent monitoring suggests partial impact (pH > 5.0 [6.97]), but bicarbonate approximately equal to 50 mg/L).

TABLE 14
Detected Constituents in Zone 3, October 2018
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Chemical Name	License NRC Standard	EPA Cleanup Level	Unit	0420	0517	0613	0708	0711	0717	0717 FD	0719	EPA 13	EPA 14	MW-7	NBL-02	NW-1	NW-2	NW-3	NW-4	NW-5	RW-11	RW-A
Section #				**36**	**36**	**2**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**	**36**
ALUMINUM	-	5	mg/l	0.69	18.0 D	502 D	36.3	20.8	277 D	273 D	2.93	0.04	13.9			-	-	0.05	-	-		0.59
AMMONIA (AS N)	-	-	mg/l	1.14	7.7 D	142 D	0.98	1.25	34 D	32 D	0.45		16 D	0.11		-	-	0.37	-	-	2.9 D	0.73
ARSENIC	0.757	0.757	mg/l	0.011		0.001					0.002	0.014		0.004		-	-	6.2 D	-	-	0.002	0.002
BERYLLIUM	0.05	0.004	mg/l		0.016	0.153 D	0.062	0.033	0.186	0.192	0.002	0.003	0.018			-	-		-	-	0.001	0.003
BICARBONATE (HCO3)	-	-	mg/l	314							44	65	55	204	322	367	115	505	16	64	132	43
CADMIUM	0.09	0.09	mg/l		0.006	0.041			0.021	0.021			0.004			-	-		-	-		
CALCIUM	-	-	mg/l	688	482	427 D	434	409	474	470	488	510	507	613	624	-	-	574	-	-	553	509
CHLORIDE	-	250	mg/l	41	34 D	116 D	26 D	21 D	57 D	57 D	30 D	44 D	48	35 D	39	15	30 D	35 D	21 D	29 D	33 D	29 D
CHLOROFORM	80	80	ug/l		3.7	53			0.56	0.61						-	-		-	-		
COBALT	-	0.391	mg/l	0.057	0.836	1.69	0.502	0.527	1.13	1.17	0.254	0.131	0.345	0.193	0.024	-	-		-	-	0.356	0.459
GROSS ALPHA	39.7	39.7	pci/l	6	10.2	20.8	14.1	9.5	15	16.3	9.1	6.3	7.4	11	6.4	-	-	27.6	-	-	11.5	18.2
LEAD	0.08	0.08	mg/l	0.003	0.009	0.005	0.006	0.052	0.041	0.021	0.002		0.009			-	-		-	-		
LEAD-210	5.7	5.7	pci/l	1.7					1.8	2.2						-	-	1.2	-	-	1.1	
MAGNESIUM	-	-	mg/l	182	584	724	566	442	492	502	731	1000	304	352	170	-	-	293	-	-	525	640
MANGANESE	-	9.1	mg/l	2.89	12.4	41.5	13	6.85	17.3	17.6	5.84	6.99	6.32	4.34	1.45 D	-	-	2.46	-	-	6.22	7.2
MOLYBDENUM	-	66.1	mg/l	1.05		0.015	0.01	0.062	0.002		0.408	0.283	0.023	0.332	0.13	-	-	0.636	-	-	0.132	0.046
NICKEL	0.569	0.569	mg/l	0.057	0.863	1.68	0.55	0.668	1.26	1.29	0.341	0.322	0.28	0.193	0.036	-	-		-	-	0.357	0.477
NITRATE (NO3)	-	190	mg/l	0.07	0.01	1.28		0.03	5.55 D	5.50 D	0.03	0.1	0.25	0.57	0.1	-	-		-	-		
PH (FIELD)	-	-	su	6.38	2.78	2.94	3.08	3.02	3.34	3.35	5.26	6.01	5.55	6.29	6.59	7.23	6.02	6.96	6.31	5.86	6.03	5.47
PH (LAB)	-	-	su	6.69 H	3.03 H		3.73 H	3.46 H	3.42 H	3.43 H	5.73 H	6.13 H	5.60 H	6.66 H	6.73 H	7.57 H	6.09 H	6.96 H	6.05 H	5.83 H	6.27 H	5.80 H
POTASSIUM	-	-	mg/l	8	14		12	9	5	5	12	14	10	10	7	-	-	9	-	-	13	12
RADIUM-226	-	-	pci/l	3.9	4.6	6.5	5.9	4.6	6.5	7.2	4.8	4.9	3.7	7.9	5.6	-	-	20.7	-	-	8	12.8
RADIUM-228	-	-	pci/l	9.7	14.4	2.8	4.7	8.1	9.4	8	13.2	9.7	6.8	7.4	7.5	-	-	9.7	-	-	15.4	17.4
RADIUM 226 & 228	35.2	35.2	pci/l	13.6	19	9.3	10.6	12.7	15.9	15.2	18	14.6	10.5	15.3	13.1	-	-	30.4	-	-	23.4	30.2
SELENIUM	0.01	0.05	mg/l	0.001												-	-	0.002	-	-		
SODIUM	-	-	mg/l	136	142 D	223 D	111 D	96 D	159 D	166 D	147 D	174 D	150 D	151 D	151 D	-	-	175 D	-	-	148 D	160 D
SULFATE (SO4)	-	5693	mg/l	2280 D	4590 D	8490 D	4490 D	3610 D	5510 D	5650 D	4580 D	5350 D	2680 D	3110 D	2190 D	-	-	2650 D	-	-	3700 D	4300 D
THORIUM-230	17	17	pci/l	0.2	5.3	790			4.8	4.2	0.3					-	-		-	-		
TOTAL DISSOLVED SOLIDS (LAB)	-	8592	mg/l	3830 D	6140 D	11100 D	6440 D	5000 D	7210 D	7300 D	6410 D	7750 D	4000 D	4620 D	3600 D	3780 D	5130 D	4250 D	4400 D	5500 D	5350 D	6090 D
TOTAL TRIHALOMETHANES	80	80	ug/l		3.7	53			0.56	0.61						-	-		-	-		
URANIUM	0.395	0.395	mg/l	0.194	0.34	0.633	0.128	0.242	0.741	0.775	0.0452	0.0103	0.0962	0.0533	0.26	-	-	0.158	-	-	0.0635	0.0206
VANADIUM	0.1	0.1	mg/l			1.01										-	-		-	-		

Blank cells indicate that the analyte was not detected
Dash (-) indicates that the analysis was not performed
Shaded values exceed the listed action level
B- Possible blank contamination
D - Reporting limit increased due to sample matrix
H - Analysis performed past recommended holding time
FD indicates a field duplicate sample

TABLE 15
Zone 1 Performance Monitoring Program, 2018 Operating Year
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Well[1]	Water Level[2]	Water Quality[2]	NRC POC	Purpose
Continue Monitoring				
515 A	X	X		Track transition area
604	X	X	Y	Track center of seepage
614	X	X	Y	Track transition area
EPA 2	X	X		Postmining-pretailings background water quality
EPA 4	X	X	Y	Postmining-pretailings background water quality
EPA 5	X	X	Y	Track transition area
EPA 7	X	X	Y	Track transition area, edge of saturation
EPA 8	X			Track edge of saturation
142	X	X		Premining background
143	X			Water level only, use 142
Additional Wells, Not Included In Original Performance Monitoring Program				
505 A	X			Long-term water level for migration path
502 A	X			Long-term water level for migration path
501 A	X			Long-term water level for migration path
504 A	X			Long-term water level for migration path
412	X			Long-term water level for migration path
Total	15	8		

Eliminated From Monitoring				Reason For Elimination
141				No longer useable, plugged during arroyo flooding
516 A			Y	Failed low-flow testing
619				Anomalous water quality and water level
615				Decommissioned pumper, not needed - use 515 A
616				Decommissioned pumper, not needed - use 604
617				Decommissioned pumper, not needed

Notes:
1. No wells within the tailings reclamation cap were included.
2. Water level and water quality monitored on a quarterly basis.

TABLE 16

Zone 1 Saturated Thickness, October 2018

United Nuclear Corporation, Church Rock Site, Church Rock, New Mexico

Well	Water Level Measurement Date	Zone 1 Unsaturated Thickness	Zone 1 Saturated Thickness	Zone 1 Percentage Saturated
0142	10/3/2018	0.00	55.00	100%
0143	10/11/2018	0.00	52.00	100%
0412	10/11/2018	0.00	76.00	100%
0501 A	10/11/2018	11.30	53.70	83%
0502 A	10/11/2018	0.00	59.00	100%
0504 A	10/11/2018	7.82	60.18	89%
0505 A	10/11/2018	0.00	46.00	100%
0515 A	10/2/2018	31.17	9.83	24%
0604	10/2/2018	28.77	16.23	36%
0614	10/2/2018	25.67	19.33	43%
EPA 02	10/3/2018	23.17	26.83	54%
EPA 04	10/3/2018	21.04	33.96	62%
EPA 05	10/2/2018	32.48	16.52	34%
EPA 07	10/2/2018	33.10	49.90	60%
EPA 08	10/3/2018	29.69	36.31	55%

TABLE 17

Detected Constituents in Zone 1, October 2018
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Chemical Name	License NRC Standard	EPA Cleanup Level	Unit	0142	0515 A	0604	0614	EPA 02	EPA 02 FD	EPA 04	EPA 05	EPA 07
		Section #		36	2	2	2	1	1	1	1	1
ALUMINUM	-	5	mg/l	0.05	0.32	0.28	0.15				0.04	0.25
AMMONIA (AS N)	-	-	mg/l		17 D		60 D	0.32	0.25	0.13	10 D	
BICARBONATE (HCO3)	-	-	mg/l	300	823	30	1550	263	280	161	46	580
CADMIUM	0.01	0.01	mg/l		0.001	0.001						
CALCIUM	-	-	mg/l	62	448	462	575	449	470	532	479	502
CHLORIDE	-	250	mg/l	17	379 D	101 D	312 D	25	24	36 D	38 D	231 D
CHLOROFORM	80	80	ug/l		240	13	172				0.65	1.4
COBALT	-	0.05	mg/l		0.023	0.085					0.045	0.08
GROSS ALPHA	15	15	pci/l	0.6	7.2	1.4	1.4	2.1	2	1.8	2.1	1.3
LEAD	0.05	0.05	mg/l		0.002		0.004		0.001			
LEAD-210	4.7	4.7	pci/l		1.4							
MAGNESIUM	-	-	mg/l	34	1340	816	678	220	219	403	470	876
MANGANESE	-	5.4	mg/l	0.038	6.9	3.39	0.914	1.74	1.76	3.03	0.178	1.96
MOLYBDENUM	-	1	mg/l	0.009			0.001					
NICKEL	0.07	0.2	mg/l		0.093	0.172	0.007				0.036	0.09
NITRATE (NO3)	-	190	mg/l	0.46	41.6 D	61.0 D	160 D	0.01	0.05	0.41	19.5 D	116 D
PH (FIELD)	-	-	su	7.77	6.13	5.5	6.52	6.95	6.9	6.78	6.23	6.21
PH (LAB)	-	-	su	7.46 H	6.24 H	5.57 H	6.57 H	7.07 H	6.76 H	6.85 H	6.10 H	6.27 H
POTASSIUM	-	-	mg/l	4	17	11	14	8	7	9	11	9
RADIUM-226	-	-	pci/l	0.5	2.4	1	0.6	1.3	1.4	1.1	1.8	0.6
RADIUM-228	-	-	pci/l	3.6	5.7	5.6	3.3	5.2	5	2.1	3.2	2
RADIUM 226 & 228	12.1	12.1	pci/l	4.10	8.1	6.6	3.9	6.5	6.4	3.2	5	2.6
SELENIUM	0.01	0.05	mg/l		0.003		0.003					
SODIUM	-	-	mg/l	343	598 D	308 D	461 D	217	210	182 D	108 D	372 D
SULFATE (SO4)	-	5539	mg/l	735 D	6510 D	4670 D	3590 D	2160 D	2150 D	3110 D	3230 D	4310 D
THORIUM-230	1.6	1.6	pci/l	0.3								
TOTAL DISSOLVED SOLIDS (LAB)	-	8020	mg/l	1330 D	10700 D	7190 D	6910 D	3430 D	3430 D	4640 D	4700 D	7770 D
TOTAL TRIHALOMETHANES	80	80	ug/l		240	13	172				0.65	1.4
URANIUM	0.238	0.238	mg/l	0.0004	0.0083		0.043	0.0016	0.0016		0.0015	0.0016

Blank cells indicate that the analyte was not detected
Shaded values exceed the listed action level
D - Reporting limit increased due to sample matrix
H - Analysis performed past recommended holding time
FD indicates a field duplicate sample

TABLE 18

Predicted Performance of the Zone 1 Natural Attenuation System, 2018
United Nuclear Corporation, Church Rock Site
Church Rock, New Mexico

Constituent	Will Standards* Be Met?		Remarks
	Section 1	Section 36	
Manganese	Yes?	Yes	Not regulated by NRC. Revised EPA standard higher than previous standard. Dependent on bicarbonate availability. No 2018 exceedances outside Section 2. Well 515A (within Section 2 boundary) typically exceeds EPA standard.
Sulfate	Yes?	Yes	Not regulated by NRC. Revised EPA standard higher than previous standard. Limited by calcium availability. No 2018 EPA standard exceedances outside Section 2, but Well 515A (within Section 2 boundary) typically exceeds EPA standard.
Chloride	Maybe	Yes	Not regulated by NRC. Recent gradually increasing chloride concentration trend at Well EPA 7 in Section 1 appears to have stabilized. No 2018 exceedances of EPA standard (250 mg/L) reported (following 2 exceedances in 2017). Exceedances typical at Wells 515A and 614 within Section 2 boundary.
TDS	Yes?	Yes	Not regulated by NRC. Revised EPA standard higher than previous standard. Governed by sulfate concentration. No 2018 exceedances outside Section 2, but Well 515A (within Section 2 boundary) concentration typically exceeds revised EPA standard.
Metals	Yes?	Yes	Attenuated by neutralization and adsorption. Well EPA 7 within Section 1 had four 2018 exceedances of NRC nickel standard (but not EPA standard) and four exceedances of EPA cobalt standard. Exceedances reported at Section 2 Well 515A (four exceedances of NRC nickel standard [but not EPA standard]) and Well 604 (nickel [one exceedance of EPA nickel standard, four exceedances of NRC nickel standard], cobalt [four exceedances of EPA standard].
Radionuclides	Yes	Yes	Attenuated by neutralization and adsorption. No 2018 exceedances.
TTHMs	Yes?	Yes	Attenuated by degradation, dilution, and dispersion. No exceedances outside Section 2. Exceedances of NRC/EPA standard in 2018 within Section 2 include Well 515A (three 2018 exceedances) and Section 2 POC Well 614 (one 2018 exceedance).

Notes:
* Based on NRC and EPA standards updated 2015